ROORKEE TREATISE

ON

CIVIL ENGINEERING.

SECTION I.

BUILDING MATERIALS.

NINTH EDITION.

REVISED BY

C. E. V. GOUMENT, C.S.I., M.I.C.E.

Late Chief Engineer and Secretary to Government in the Public Works Department, United Provinces, India.

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PREFACE.

This manual has been entirely rewritten. The original edition has been utilised as far as possible and a good deal of information has been obtained from the latest English publications on the subject. The author is chiefly indebted to Rivington's Notes on Building Construction and " Building Materials " by Middleton, published by B. T. Batsford, High Holborn, London: These two books are strongly recommended to young Engineers who require more detailed information than it has been possible to give in this elementary text-book.

C. E. V. G.

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CHAPTER I.

INTRODUCTION.

Before discussing in detail the materials employed for Engineering structures, it will perhaps not be unprofitable to review very briefly the leading facts in the past history of our earth from which these materials are derived so far as these are known to scientists at present or have been assumed by them as working hypotheses.

2. The Solar system to which our earth belongs consists of the sun at the centre and several planets revolving round it with their satellites. There are several theories which attempt to explain the origin of the Solar system. Of these, Laplace's theory seems to fit in best with observed facts and is now generally accepted. According to this theory, our Solar system existed originally as a revolving mass of nebulous matter composed of incandescent gas. As this fire cloud revolved in space it gradually cooled and contracted until its outer edge had reached so low a temperature that it could no longer remain in its vapour condition and condensed into a liquid globe. This globe of red hot revolving matter continued to lose its heat and formed the outermost planet of our system. So one after another the different planets condensed from the vapour cloud and in course of time cooled down to such an extent that they ceased to be luminous and assumed their present appearance. Our earth is one of these planets. The sun at the centre of the system is the remnant of this cloud and is still in a highly incandescent state emitting light and heat. The planets themselves are non-luminous and the light by which they are seen from our earth is sunlight reflected from their surfaces.

3. There are only eight planets in our Solar system revolving at varying distances in elliptical orbits round the sun. All the other visible stars in the sky are so-called "fixed" stars each of which shines by its own light and, like our sun, is probably the centre of a system. The stars are said to be "fixed" only in the sense that being at vast distances from our system they *appear* to be fixed as compared with our planets which revolve rapidly with us round the sun and are therefore constantly changing their positions in the sky as seen from our earth.

Our sun and the stars are really not fixed in the sense of being stationary; they are believed by astronomers to be travelling through space at an enormous speed but little or nothing is known at present of the laws which govern their flight. Besides the stars, there are many

other objects discernible in the sky, such as nebulae, star clusters, comets, meteors, etc., which cannot be described in this very brief review.

4. As regards the origin of the nebulae from which solar systems are derived, it is now assumed by some of the leading astronomers that they are produced by violent collision between cooled and solid stars flying through space at enormous velocities, the heat generated by the collision being so intense that it immediately converts the solids into incandescent gas or nebulous matter. In such collisions, the chances are against the bodies striking together centrally, it being much more likely that they hit one another rather towards one side. The nebulous mass thus produced would therefore come into being with a spinning tendency which accounts for the revolving movement these nebulae are known to have.

5. Spectrum analysis has revealed to us the interesting fact that the sun and stars are composed of elements similar to those which go to make up our earth.

6. After our globe had assumed the liquid condition as explained above, the process of cooling still continued with consequent contraction and in course of time the vast ball of molten matter was covered with a solid crust or skin. For many ages the surface of the earth was too hot to permit the formation of water from its constituent gases but when the cooling had proceeded sufficiently to allow of this, that large body of water which fills our oceans came into existence and covered the surface of hard bare rock from pole to pole. While the crust was still thin and yielding, it was subject at intervals to alternate upheaval and depression owing to further contraction. These movements raised some parts, producing the hills and plains of our dry land, and depressed others to form deep lakes, seas and oceans. These forces are still in operation but the crust being now of a great thickness, the movements are so gradual and slow as to be hardly perceptible.

7. After the separation of land and water on the earth's surface, the various disintegrating influences tending to alter its configuration which are still existing, came into operation. The tides, ocean currents, rivers, streams, the rain, the atmosphere, all began their action on the primary rocks of the original crust, wearing them down and redistributing their particles in homogeneous order along the ocean beds, forming stratified rocks which imbedded the organic remains of the animal and vegetable life which began to appear on the now habitable earth. There is abundant evidence to show that all rocks exhibiting stratification have been deposited by aqueous action—that is that the particles of which they

are composed were once mixed with water and gradually sank to the bottom of the sea or lake where in process of time they became solidified and appeared on the surface either by the draining off of the water or by the upheaval of the bed from the causes above referred to.

8. The formation of the surface soil and rocks of the earth has probably been perfectly uniform and geologists have therefore found it convenient to classify the different series of stratified rocks according to the chronological order in which they were formed. The points to be considered in deciding the geological epoch to which any particular stratum belongs are (1) its order of superposition, (2) the organic remains of life, called fossils, imbedded therein.

9. If two strata are discovered, one lying on the other, we may at once infer that the lower one was deposited before the other. This holds good uniformly in a *relative* sense but it cannot always be inferred that any one stratum was deposited *immediately* after another just below it as owing to the varying conditions affecting deposition and upheaval in different places it will often happen that several intervening strata have been formed by these means in the interval at other places which do not exist between the two strata under consideration. The order of superposition therefore determines the *relative* times of deposition of the series of rocks but it does not establish an exact order of sequence of the different series which is universally applicable.

10. The fossils in a rock are the surest of all tests of age. The same fossils may be found in several succeeding strata but every strata has some fossils peculiar to itself by which it is at once known and referred to its proper position. A knowledge of Paleontology is therefore absolutely necessary to a geologist.

11. The three main heads under which rocks are now classified are (1) Igneous, (2) Metamorphic, (3) Stratified.

12. **Igneous rocks** come from the original crust formed by the action of fire—where these appear at the surface they have in most cases been forced up in a molten state through vents in the stratified rocks which once overlaid them, these vents having been produced by the buckling of the surface strata due to contraction. If the molten mass has burst out in a volcanic eruption and, mixing with air, it has poured out as a stream of lava, it has produced on cooling the compact rocks known as basalt and trap. If, however, instead of bursting out it has cooled gradually in clefts below the surface, its constituents have formed themselves into crystals and produced the solid crystalline rock known as granite. Such rocks contain no fossils.

13. **Metamorphic** rocks were probably at one time sedimentary and stratified but by the action of heat subsequently applied their appearance has changed and become more or less crystalline. No fossils have as yet been discovered in these rocks nor can this be a matter of surprise as a re-arrangement of particles or "metamorphosis" would naturally obliterate any fossil remains if there ever were any. The metamorphic action has not been carried to the same extent in all rocks. They are therefore divided into two classes—(1) Those in which the original structure is still apparent, (2) Those in which it is non-existent.

Among the former may be included quartzite, clay slates and marble. Among the latter, schists and gneiss. The two most prominent varieties of the metamorphic group are marble and gneiss. The former is an altered or metamorphosed limestone. The latter, having the appearance of a degraded granite, consists of the same constituents as granite, viz. mica, felspar and quartz, but it shows a more or less laminated arrangement of its particles, while granite is solid and homogeneous. Slates are originally of sedimentary origin being formed of clay or silt deposited in thin layers in shallow water. Subsequent buckling of the surface due to contraction by producing great pressure and consequent heat, has compressed them into hard thin slabs obliterating all visible signs of the original stratification and substituting another at right angles to it which is known as their planes of "cleavage."

The metamorphic system provides many of our most valuable materials. Marbles, slates, quartz, anthracite, copper, lead and tin are found in this system. Gold and silver and many precious stones, including diamonds, are also among the valuables its beds contain.

14. Above the metamorphic rocks come the true sedimentary strata which are preserved in the condition in which they were deposited except that they have in places been tilted and upheaved by igneous agency from beneath. These strata consist chiefly of sandstones, limestones and shales which underlie the recent surface deposits of gravel, clay and sand. They are fossiliferous and are classified by geologists as above explained in chronological order according to the epochs in which they were originally deposited. It is not possible in this introductory chapter to give detailed information regarding their classification, the characteristics of the rocks and minerals found in each series, their fossils, depth of beds, etc. Students will acquire this information in going through their College course in Geology and Mineralogy and if still fuller details are required they will find all they need in "Geology of India" by Medlictot and Blanford, published by the Government of India.

CHAPTER II.

STONE.

15. **Selection of stone for building.**—The points to be considered in selecting a stone for a building or other engineering structure are appearance, durability, strength, hardness and the readiness with which it can be dressed by masons into the various shapes in which it is required.

16. **Appearance.**—The appearance of a stone is often important, especially in the face work of large buildings which are intended to be architecturally beautiful. The colour of the stone used should harmonise with the surroundings as far as possible and the variation of colour in the different parts should be such as to produce the architectural effects desired. A good weathering stone should be selected free from flaws, clayholes, etc., and all varieties containing much iron should be avoided as these are liable to disfigurement from rust stains caused by the oxidation of the iron under the influence of the atmosphere.

17. **Durability.**—The durability of a stone depends upon its chemical composition and its physical structure but it varies greatly according to the nature and extent of the destructive influences to which it is subjected in different localities. The chemical composition should be such that it will resist the action of the atmosphere and of the deleterious substances which, especially in large cities, the atmosphere often contains. These destructive substances are taken up by the moisture in the air or by rain and are thus conveyed into the pores of the stone. A stone which will weather well in the pure air of the country is often rapidly destroyed in the smoke of a large town. The sulphur acids, carbonic acid, hydrochloric acid and nitric acid in the smoky air of large towns are particularly injurious to stones consisting of a large proportion of carbonate of lime or carbonate of magnesia and the fumes from bleaching works and factories of different kinds soon destroy stones whose constituents are liable to be affected by the particular acids which these fumes contain. The texture of the stone is also an important factor in its resistance to wear. Stones which are crystalline in structure or homogeneous and close grained with good cementing material have a higher resisting power than those which are porous or those which contain patches or streaks of soft material. Examination of a recent fracture through a magnifying glass and mechanical or chemical tests are helpful

to a certain extent in investigating the durability of a stone but, whenever possible, it is safer to be guided by the weathering effects observable in old structures built of the same stone in the immediate neighbourhood or under the same conditions.

18. **Strength.**—The strength of stone is not ordinarily a matter of much consequence, if it is suitable in other respects, as the compression to which it is subjected in an ordinary structure is never sufficient to cause any danger of crushing. If, however, it is to be subjected to any excessive or unusual stresses, the strength should be ascertained by experiment. It is generally laid down that the compression to which a stone should be subjected in a structure should not exceed $\frac{1}{10}$th of the crushing weight determined by experiment. Stones in ordinary works are generally under compression occasionally subject to cross strain, but never to tension.

19. **Hardness.**—The hardness of stone is of importance, if it is to be liable to a considerable amount of friction and wear, as in pavements, or if it is to be used for quoins, mouldings and other positions where it is particularly necessary to preserve a sharp angle or edge. Hardness combined with toughness is also essential in stone used for road metal. Stone used in positions where it will be exposed to the action of running water should also be selected for hardness, as water in motion soon wears away the surface of any stone which is not of the hardest description.

20. **Easily dressed.**—The ease with which stone can be cut or dressed by masons into the different shapes in which it is to be used is an important consideration from the point of view of economy. Its suitability in this respect will depend upon its hardness, the uniformity of the texture and its freedom from flaws, shakes, vents and other imperfections. For carved work stone should not be too hard or laminated while a hard stone in comparatively thin layers, easily separated, would be quite suitable for ordinary rubble masonry.

21. **Natural bed.**—Stratified stones should always be placed in walls subject to vertical pressure on their *natural beds*, that is, in the position in which they were *originally deposited*. If they are placed with their natural beds parallel to the face of the wall, the effects of wet and frost will scale off the face, layer by layer, and rapidly destroy the stone. In arches, stones should be placed with their natural beds at right angles to the direction of the thrust on them. A stone placed with its natural bed normal to the pressure on it is capable of bearing a much greater compressive stress than if the stratification is at right angles to the bed joints.

In cornices with undercut mouldings the natural bed should be placed vertically and at right angles to the face, for, if placed horizontally, the lower layers of the projecting part would be liable to drop off.

22. Classification.—Stones are classified under the three main heads, igneous, metamorphic and stratified as explained in the Introductory Chapter.

The Igneous stones used for engineering works in India are granite, basalt and trap; the metamorphic rocks, marble, gneiss and slate; the stratified rocks, sandstone and limestone. Each of these will be briefly described in the following paragraphs:—

23.—**Granite.**—Is a very strong and durable stone and, though hard, it takes a fine polish. It is composed chiefly of quarts and felspar mixed with particles of mica. The colour depends upon that of the predominating constituent, felspar; it is usually grey or reddish brown. In good granite the felspar should be crystalline and lustrous, not earthy, in appearance. The quartz is a hard glassy substance in grey or colourless amorphous lumps, occasionally in crystals. Mica is in semi-transparent glistening scales of a dark grey or brown colour.

On account of the difficulty in working it to the shapes required, granite is only used where great strength and durability are absolutely necessary and expense is no object. In buildings it is reserved for ornamental features such as polished columns, heavy plinths, pedestals of statues, etc. A good example of it may be seen in the pedestal of Mr. Thomason's bust in the centre of the college corridor. There are a few good quarries of this stone in Southern India.

24. **Basalt and trap.**—Are found in Central India but are little used structurally being very hard and difficult to work and sombre in colour. They make good road metal and, when split up by joints, may be utilised for paving setts.

25. **Marble**—Consists generally of pure carbonate of lime. It is very hard and compact and takes a fine polish. The texture, degree of crystallisation, hardness and durability vary considerably in different varieties. The handsomer kinds are too expensive for use except for statues, chimney pieces, inlaid work, table slabs, etc. The less handsome varieties are used for buildings in the neighbourhood of quarries, but they are not usually considered to be worth the cost of transport to great distances for this purpose. The usual colour of marble is white but it is sometimes yellow, red or black. In India it is found

in the Jeypore State, Rajputana. Good examples of it may be seen in the busts of Mr. Thomason and Colonel Cautley in the College corridor.

26. **Gneiss.**—This is a rock which has the same mineral constituents as granite but it is more or less stratified. It is very little used in building. The harder varieties are sometimes used for the interior filling of thick walls faced with stone of a superior quality and for road metal. In India gneiss is found in Bengal and Madras and in certain localities in the Himalayas.

27. **Slate.**—The ordinary slate used for roofing and other structural purposes is a metamorphosed argillaceous rock, compact and fine grained. It was originally a sedimentary rock formed by deposits of clay but its texture has been altered by heat and intense pressure to such an extent that it will no longer separate along the planes of original bedding but splits readily along planes at right angles to these planes called "planes of cleavage." This characteristic is one of the most valuable that slate possesses as it allows of blocks being split into thin smooth sheets which provide a very useful light and impervious roof covering.

A good slate should be hard and tough and it should not absorb water to any appreciable extent. It should be very fine grained and give out a sharp metallic ring when struck with the knuckles or a light hammer. The colour varies greatly but it is usually grey or dark blue.

Besides the small thin slates used for roofing, large and thick slabs are obtained from some quarries which, being very hard and strong, are used for buildings and other engineering works. Such slabs are sedimentary argillaceous rocks only slightly metamorphosed. Being regular in shape they can be fitted with accuracy and are useful for flooring flags, steps, landings, mantelpieces, windows and door sills, urinal partitions, baths, cisterns, etc.

Slates in India are found in Rajputana, Chamba, Kangra Valley and Rewari near Delhi.

28 **Limestones.**—There is a great variety of these stones, from pure carbonate of lime to magnesian limestone, which is half carbonate of lime and half carbonate of magnesia. They are generally found in combination with a small proportion of sand or clay. The colour varies; it may be white, yellow, grey, dark blue or mottled.

Compact limestone, consisting of pure carbonate of lime is burnt to produce white or fat lime. If it contains a considerable amount of clay it produces, when burnt, hydraulic lime which is capable of setting under water. Compact limestone, either pure carbonate of lime or mixed with

a small proportion of sand and clay, is very useful for paving sets or road metal under light traffic. It is also used as flux in blast furnaces and for bleaching, tanning and other industrial purposes. Limestone of this variety is good for building purposes if it can be obtained of a tough durable quality and not too hard to be easily cut and dressed by masons. It is liable to be injured by acid atmosphere, and by frost, but otherwise its weathering qualities are good.

Granular limestone consists of grains of carbonate of lime cemented together by the same material or by a mixture of carbonate of lime with silica or alumina. The grains vary greatly in size being as large as peas in some varieties. Their colour is usually white, yellow or light brown. Granular limestone is generally soft and can easily be worked to any shape. It is fairly durable if not exposed to frost or acid atmospheres. If not too soft it makes a very good building stone. It is often quite soft when first taken out of the quarry but hardens on exposure to the air.

Magnesian limestones are composed of carbonate of lime and a large proportion of carbonate of magnesia with a small quantity of silica and alumina. They are known as *Dolomite* if they contain lime and magnesia in about equal proportions. The colour is usually yellow or light brown. The harder varieties are useful for building purposes if they contain a large proportion of carbonate of magnesia and very little silica. They are, however, peculiarly liable to disintegration in an atmosphere charged with sulphuric acid which forms a soluble sulphate of magnesia. They should therefore be used with great caution in localities where the air is charged with acid fumes or smoke.

Limestone is found in all parts of India in hilly regions.

29. **Sandstone.**—Being of purely sedimentary origin sandstone shows distinct stratification and consists generally of grains of quartz, i.e. sand, cemented together by lime, magnesia, silica, alumina, oxide of iron or by mixtures of these materials. Besides the grains of quartz there may be other substances such as flakes of mica, fragments of limestone, argillaceous and carbonaceous matter interspersed throughout the mass. The grains of quartz being practically imperishable, the weathering quality of any particular variety depends entirely upon the resisting power of the cementing substance under the conditions to which it is subject. For external building work, the finer grained sandstones are stronger and more durable as a rule than those of coarser grain. The hardest and best sandstones are used for important ashlar work; the

fine grained variety for carved work and mouldings; the rougher sort for rubble masonry; and the highly stratified varieties for flag stones. The very hard qualities are used for paving setts and for road metal but under heavy traffic they are inferior to the tougher materials. Roads metalled with sandstone are usually muddy in wet weather and very dusty in dry weather. In buildings, sandstone should always be laid on its natural bed. The colour varies greatly; it may be white, yellow, grey, brown, red or dark blue.

Like limestone, this variety of stone is found in hilly regions in all parts of India.

30. **Kankar.**—This is a most useful material for road metal and for burning into hydraulic lime. It is a hard spongy deposit of lime and clay which is found a few feet below the surface in the alluvial soil of Upper India. It is khaki in colour and its texture is open and porous. If is found either in a solid layer from a few inches to several feet in thickness or in separate nodules disposed in a horizontal layer at various depths under ground. The nodular variety, containing a larger proportion of clay, can only be used for road metal or for burning into lime, but block kankar, if hard, makes a fairly good durable stone and is sometimes used for foundations of buildings. Kankar used for road metal should be hard, clean and tough; the softer varieties containing a large proportion of earthy matter are unsuitable for roads under heavy wheel traffic.

31. **Preservation of stone.**—Several means of preserving the less durable stones have been tried from time to time but no really satisfactory process has yet been discovered. It is better to use a good durable stone or brick in the first instance than to trust to preservatives. The most common method adopted is painting the exposed face with lead paint or with oil to fill the pores and make the stone more impervious and better able to resist atmospheric influence. It is not necessary to give a description of such preparations in detail. "Sczerelmy's liquid" has been used a good deal for this purpose but it is more valuable for rendering absorbent stones somewhat waterproof than for preserving them.

32. **Artificial stone.**—The expense of making artificial stone precludes its extensive use for ordinary purposes but the facility with which it can be moulded into the most intricate forms makes it very economical sometimes when it is required to take the place of carvings or other ornamental features in natural stone. Most artificial stones are composed of granite or other very hard stone ballast, broken very small, and a

matrix of Portland cement. They are either laid *in situ* or cast in moulds. The only advantage they possess over ordinary concrete is that the material is very carefully selected and mixed and they are made by workmen who are specially skilled in this class of work. Some makers subject the moulded slabs, after they have been made, to a hardening process by immersing them for several weeks in a solution of silicate of soda.

The processes of manufacture are generally patents. The best known English varieties of artificial stone are Ransome's, Victoria, Imperial and Stuart's granolithic stone. It is not possible to describe them all in this manual but the following description of the Victoria stone will give a rough idea of the process of manufacture generally adopted.

Victoria stone consists of finely powdered washed granite bound together by the best and strongest Portland cement. A mixture of four parts of crushed granite and one part of cement is allowed to set in a mould for three days till it becomes a hard block. It is then immersed for 7 or 8 weeks in a solution of silicate of soda which is prepared by boiling ground Farnham stone in cream caustic soda. The lime in the cement combines with the silicate and the whole mass is indurated by the silicate of lime thus formed.

This artificial stone is commonly used in England for paving, window sills, coping stones, pier caps, stairs, sinks, troughs and tanks.

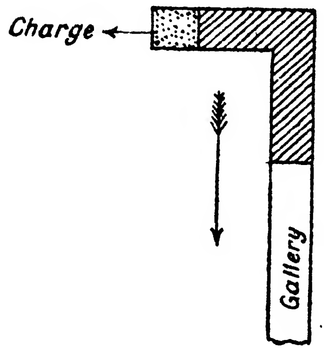
A very useful artificial stone for floors is now made in India by the Indian Patent Stone Company, Calcutta. See paragraph 61 of the Manual of Building Construction.

33. **Quarrying.**—The engineer may be so situated in India that he may have to quarry his own stone. The following hints will therefore be useful:—

If the operations are to be on a large scale the first thing to be done is to prepare a plan on a large scale showing clearly the position of the quarry, the ground on which the quarried stone is to be rough dressed and stacked prior to despatch, the position of the spoil heaps where the quarry refuse is to be deposited, the roads and other means of communication, if any, between the different working areas.

If the rock to be quarried is covered by a thick cap of soil or loose stone, it will first be necessary to remove this covering before the stone can be attacked. In order to do this, it may be necessary to explode large charges of powder at suitable points in the body of the hill near the rock face to loosen and break up the covering cap and enable it to be

readily removed. These charges are usually laid in a short return at the end of passage or gallery driven into the hill side of a size sufficient to allow of the easy passage of workmen to and fro. The object of placing the charge in the short cross gallery at the inner end is obviously to bring the force of the explosion to bear on the mass to be shaken up and prevent the charge being blown out through the straight gallery. When the charge has been laid, the return is built up as also a short length of the gallery at the inner end.



If the quarry is to be commenced on a bare rock face or where the rock has been laid bare by removal of its cover cap the stone should be closely examined to find the natural joints or fissures or lines of cleavage, if any. All stratified rocks will be found to have joints or fissures at which the stone has little or no natural adhesion and can be readily divided into blocks. A wide recess should first be cut into the rock for a good depth from the face to show the joints or fissures at the back. When this has been done, the size and position of the contiguous blocks will be exposed and a commencement can then be made with the quarrying of the stones on both sides. If the rock is not very hard and it is distinctly stratified and fissured, it will be possible to remove it by picks, crowbars and the quarryman's hammer. If too hard and compact to be dealt with in this way it must be quarried in blocks by cutting grooves or boring holes at regular short intervals in the upper surface of a bed, inserting blunt wedges in the grooves or conical pins in the holes and driving these with a hammer until a block splits off from the layer.

34. **Blasting with powder.**—If large masses of stone have to be quarried and the stone is of a compact nature or in very thick beds, the process of blasting becomes necessary. If this is resorted to it should be borne in mind that its object is to loosen and break up the mass to render it easy to work and not to blow the material about violently and split all the good stone into useless small pieces.

The implements used in blasting are of a simple character and consist of the *jumper*, the *scraper* or *spoon*, the *priming needle* and the *tamping bar*. The *jumper* is used for making the blast holes. It is an iron bar of variable length and diameter according to the depth and size of hole required for the blast. Its ends are knife edged and tipped with steel. The *scraper or spoon* is an iron rod having one of its ends beaten out and curved to form a groove like a half hollow cylinder, the lower end being closed by a semi-circular disc. It is used for removing the dust and chips formed by the action of the jumper from the bottom of the hole. The *priming needle* is a long thin iron rod about $\frac{1}{16}$ inch diameter which is inserted into the charge after it has been placed in the hole and remains in position while the hole is filled up with tamping material so that, when ultimately withdrawn, a channel is preserved communicating with the powder. It has a loop handle at one end and is pointed at the other. The *tamping bar* is a heavy brass rod of a diameter less than that of the blast hole and slightly tapering at the extremities. At each end an open groove is formed along the side to admit of the bar being used with facility while the priming needle is still in the hole.

The operations which constitute the process of blasting are boring the holes, loading and firing. The holes are bored by means of the jumper in ordinary quarrying. If the work is on an extensive scale, the rock is exceedingly hard and time is an important object, it may be necessary to use rock boring machines worked by steam or air pressure, but these are not often employed for open stone quarries, their use being restricted to excavation of tunnels or galleries (for which ordinary jumper work is not suitable owing to the cramped space in which the work is done and the angle at which the boreholes have to be made. A detailed description of these machines will therefore not be attempted in this Manual but students requiring further information will find it in full detail in the Supplement to Spon's Dictionary of Engineering.

In using the jumper, one man sits down on the rock in a convenient posture and holding the lower part loosely directs it so that it strikes fairly in the hole. Another man stands upright and raising the jumper a foot or so above the surface drives it home forcibly into the hole. At intervals, a little water is poured in to soften the rock slightly and to convert the dust etc. formed in the hole into a paste which is readily removed from time to time by the scraper or spoon.

After the hole has been made to the required depth, the charge has been deposited in it and the priming needle placed in position, it is filled

up again or *tamped* with the damp clay. The tamping material should be firmly rammed in by means of the tamping bar to offer as much resistance as possible to the explosive force of the powder and direct its action towards *the line of least resistance* which is measured from the centre of the charge to the nearest surface of the rock. It should be put into the hole in small quantities sufficient to fill from an inch and a half at a time which should be well rammed home before the next lot is put in. It is advisable to grease the priming needle well before tamping is commenced and to turn it occasionally during the process to facilitate its withdrawal when the tamping is finished.

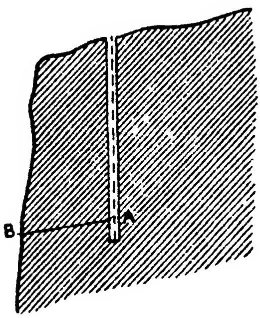
The priming needle being withdrawn, the space occupied by it is filled with fine powder (sometimes confined in a straw or reed) and this is fired by means of a slow fuze made of paper or linen soaked in a strong solution of nitre or gunpowder. This fuze should be so arranged and of such a length that the person firing it will have ample time to retreat to a safe distance before the charge explodes. Bickford's Patent fuze is very reliable and is generally used for this purpose.

If the rock is very hard and rapidity of execution is an important object, electric firing is sometimes resorted to by means of patent electric fuzes and portable firing batteries. These will not be described in this manual as they are usually employed for excavation of tunnels or galleries and not for ordinary quarry work. When this system is adopted a large number of shots can be fired simultaneously which economises time and labour to a considerable extent. For a detailed description of this method of firing see Supplement to Spon's Dictionary of Engineering.

The useful effect of a blast will depend in a great measure on the judicious selection of the position of the blast holes. If these are placed too far back from the working face the effect of the explosion will be merely to blow the charge out through them instead of breaking up the stone in the direction of the face along a *line of least resistance.*

The *line of least resistance* is that line by which the explosion of the charge will meet with the least opposition to its vent in the air. This need not necessarily be the shortest line to the surface. A long line in earth or soft rock may offer less resistance than a shorter line in hard stone. Supposing the material to be of uniform consistence in every direction, charges of powder to produce similar results ought to be as the *cubes* of the lines of least resistance. Thus if 4 ounces of powder have a given effect upon a solid mass of rock 2 feet thick to the face, it will

require $\left(\frac{3^3}{2^3} \times 4\right)$ or 13½ ounces to produce the same effect upon a mass of rock 3 feet thick. These quantities, if common blasting powder is used, will be found sufficient for ordinary rock, but it is safer in each case to ascertain by a few experiments the precise quantity required for the particular rock to be dealt with for any given thickness and to calculate the amount required for other thicknesses in the same rock. Thus, with a 2-foot line of least resistance (AB), if 4 ounces are required to produce the desired effect, 13½ ounces will be required for a 3-foot line; if 6 ounces are found necessary for a 2-foot line, the charge for a 4-foot line will be $\frac{4^3}{2^3} \times 6$ or 48 ounces, and so on.



The above directions are for working with ordinary blasting powder but they are generally applicable *mutatis mutandis* to other explosives. Gun-cotton and dynamite are sometimes used for blasting purposes. These are more expensive than powder but are much stronger. The relative strength of powder, gun-cotton and dynamite, bulk for bulk, is as 1 to 2½ to 4 respectively.

35. **Composition of explosives.**—Blasting powder is a mechanical mixture of saltpetre, suplhur and charcoal in the proportions 65, 20 and 15. Gun-cotton is a chemical compound consisting of carbon, hydrogen, oxygen and nitrogen $(C_6H_7O_2)O_3(NO_2)3$; it is made by soaking cotton waste in a mixture of nitric and sulphuric acids. Dynamite contains 75 per cent. of the explosive oil called nitro-glycerine, $C_3H_5(NO_2)3$ absorbed in a silicate earth with which it forms a semi-plastic paste.

36. **Gun-cotton.**—Gun-cotton requires a much lower temperature for its ignition than blasting powder—185°C as against 250°C. When dry it can be fired by striking it with a steel hammer on an anvil. When *wet* it cannot be exploded by the heaviest blows. Only a powerful detonation will produce an explosion when in the wet state. It is also not inflammable in this state. A hole may be bored through a block of *wet* gun cotton with red hot iron without igniting it, a quality which renders it the safest of explosives as it can be stored wet in closed vessels and dried as it is required for use or even used wet with a small primer cartridge of dry gun-cotton. When ignited in *small quantities* in an unconfined space it burns fiercely but does not

explode. For blasting purposes, gun-cotton is used in a compressed state with a detonating fuze charged with fulminate of mercury. Being an unstable compound, the sympathetic vibration set up in it by a sharp and sudden detonation either in contact with or close to it has the effect of producing its instantaneous decomposition or explosion. The action of gun-cotton is very violent and, as its effect is rather to shatter the rock to pieces than to move it out in large blocks, it is not so suitable as a rule for quarrying operations as blasting powder. But for ordinary mining operations and tunnelling, where very strong tough rock has to be removed, its violent shattering action is more useful as it tends to break the rock up into small pieces whereby its removal is greatly facilitated.

37. **Dynamite.**—This explosive is even less suitable than gun-cotton in cases where it is required to blast the stone out in large blocks owing to its more violent action and greater shattering effect but in very tough rock which it is merely intended to remove it is considerably more effective and it will often bring out rock which gun-cotton fails to loosen. Dynamite is not affected by water so that it can be used under water or in wet holes. Water is commonly used as tamping with this explosive and in upward holes where water cannot of course be used it can be fired without tamping as its quick action renders this unnecessary.

Dynamite is always fired by means of a detonator which consists usually of six to nine grains of fulminate of mercury in a copper cylinder. The detonator is fired either by a length of slow burning fuze or by electricity. The pasty form of dynamite makes it very useful for blasting as it can be readily rammed into the boreholes to fill up all inequalities. This also renders it safe to handle as blows can hardly produce sufficient heat in it to cause explosion. A small quantity will explode under a severe blow on an anvil but a large quantity cannot be exploded by a blow owing to the cushioning effect of the absorbent earth If ignited in small quantities in an unconfined space it burns without explosion.

38. **Storing Explosives.**—The storing of explosives is a matter of very great importance. A proper magazine apart from dwellings or other important buildings should be specially provided, no two explosives should be kept in the same box and detonators for such explosives as require them should be kept entirely apart until wanted for use.

39. **Dressing.**—The large rough blocks obtained from the quarry have to be dressed down to the shape and size required for the work The tools chiefly used by a stonecutter are the *chisel*, *hammer* and *axe*

A complete set of these tools may be seen in the College Museum. For ordinary rubble masonry the stones are cut down to the size required with flat beds and approximately vertical sides, the face being left rough, but for ashlar work where a smooth surface is necessary, the faces must be dressed true and square and even. The usual method of dressing to a smooth surface is to cut various channels or *draughts* with a chisel and hammer round the edges of the face to be dressed and across it and then to work down the intermediate portions to the same depth as the draught. The harder stones are generally *tooled*, that is the marks of the chisel are left on the face. If these marks are carefully made in parallel lines the work is called *fair-tooled*; if anyhow, it is called *random-tooled*. Softer stones are reduced to a fair surface with various descriptions of tools which need not be described here as they vary in different localities. If a very smooth surface is required, the faces, if the stone is not very hard, are rubbed with sand.

CHAPTER III.

BRICKS.

40. **General description.**—Bricks are made of tempered clay formed in a mould to the requisite size and shape and dried in the sun. In this condition they are called sun-dried bricks, or, in Hindustani, *Kachcha.* Such bricks are commonly used for unimportant and temporary buildings but, for permanent works, the bricks are hardened by being burnt in a kiln. When thus treated they are called burnt bricks; in India, *pukka.* On account of imperfections in the application and distribution of heat in a kiln, it seldom happens that all the bricks put in are fired exactly to the required extent. Some are only partially burnt and these, from their generally yellowish tinge, are known as *pila* bricks. Others are overburnt and become distorted. When the overburning has proceeded to a great extent they are found partially fused and in lumps frequently of large size. These lumps of overburnt bricks are called *jhama.* If the brick earth contains a large proportion of sand these masses of brick are more or less vitrified and when cool are dark coloured, hard and brittle.

A sound and well burnt brick is so hard that it is not possible to make a scratch or dent on the surface with the finger nail, it emits a clear ringing sound when struck and is generally of a clear and uniform colour. The colour depends chiefly on the nature of the clay of which it is made but also to some extent on the kind of fuel used. Bricks of a deep red colour are generally good.

An underburnt brick does not weather well in exposed positions, it is incapable of withstanding the action of water and is therefore quite unsuitable for hydraulic works or damp positions; it cannot stand much pressure and, owing to its ready absorption of moisture from the air, it is very liable to be affected by the action of saltpetre or other salts which, on crystallizing, cause the brick to crumble away.

The absorption of a good well burnt brick after six hours immersion in water should not exceed $\frac{1}{10}$ of its weight when dry. Its strength to resist crushing is from 800 to 1,000 lbs. per square inch Its weight is about 120 lbs. per cubic foot.

41. **Constituents of brick earth.**—The earths commonly used for brick making consist generally of alumina and silica, either alone or in combination with other substances such as lime, magnesia, iron, etc. Without going into the chemistry of the subject it will perhaps be useful to just glance at the effect each of these constituents has on the bricks in the processes of moulding and burning.

Alumina is the chief constituent of nearly every kind of clay. It makes the earth plastic but it shrinks and cracks in drying, warps and becomes very hard under the influence of heat.

Silica exists to some extent in all clay either in chemical combination with the alumina as silicate of alumina or in an uncombined state as sand. Alone or in the presence of alumina only, it is infusible except at very high temperatures, but if silica and alumina are in nearly equal proportions the presence of oxide of iron renders them fusible at comparatively low temperatures. Pure silicate of alumina is plastic but shrinks in drying and warps with intense heat. Sand on the other hand prevents shrinkage, cracking and warping, but if in excess it renders the brick too brittle.

Lime, if present, has a two-fold effect. It reduces shrinkage in drying but it acts as a flux in burning and causes the silica to melt, thus binding the particles of the brick together. It should, however, be present in a very finely divided state ; if in lumps it is most injurious, as when burnt these lumps become quicklime which expands in the body of the brick by absorption of moisture and causes disintegration. Pieces of quicklime of the size of pinheads have been known to detach portions of a brick and split it to pieces.

Alkalies, when present to a considerable extent in clay, make it unsuitable for bricks. They act as a flux and cause the clay to melt and lose its shape. Common salt has much the same effect. "Reh" (nitrate of soda, is particularly objectionable, if present in appreciable quantity, as being efflorescent, it exudes in a damp situation and disfigures the work.

Oxide of iron, when in the presence of silica and alumina mixed in nearly equal proportions, renders them fusible. It also influences the colour of the bricks producing a tint which varies from *light yellow* to *orange* and *red*, the colour increasing in intensity according to the proportion of iron contained in the clay. If the iron is present in large quantities (8 to 10 per cent.) and the brick is raised to an intense heat, the red oxide of iron becomes black oxide and combining with the silica produces a *dark blue* colour. If a small quantity of manganese is present with the iron, the brick becomes darker still or even *black*.

Magnesia in the presence of iron makes the brick *yellow*. Lime with iron produces a colour varying from *cream* to *brown*.

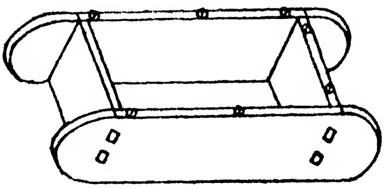
42. **Preparation of brick earth.**—The first part of the process of brick making is the preparation of the clay. It should neither be very stiff nor very loose and sandy. If the former, the bricks are liable to crack in drying and are more likely to be imperfectly burned ; if the latter, they are soft and brittle and more apt to fuse in burning. Clay with an admixture of gravel or pebbles should be avoided as a rule ; if used at all it should be carefully crushed between rollers to pulverise the pebbles. Lime pebbles, as explained above, if burnt in a brick, slake afterwards and split the brick. If gravel is present the brick cannot be readily cut or worked.

The tempering of the clay before it is moulded into bricks is an important part of the process and should be carefully supervised, as the ultimate success of the manufacturing operations depends on it to a great extent. In England the clay is dug up and kept in heaps for months before it is used for moulding in order that it may be thorougbly weathered by sun, wind and rain, but this is rarely possible in India nor is it absolutely necessary as excellent bricks can, with proper precautions, be made of soil which has been dug a few days only. The usual practice in this country is to dig the earth a week or so before it is required for moulding, break it up thoroughly, water it and knead it well under foot till it becomes a homogenous mass. It is then covered up with cloths or mats and left to dry gradually till it is of the right consistency for moulding. For very superior bricks required for arches, columns and mouldings, the earth is prepared in pug mills a description of which will be found in the chapter on Tiles.

43. **Moulding.**—When the clay is thoroughly prepared as above described the moulding commences.

The bricks may be made of any size but in all cases the breadth should be rather less than half the length so that one stretcher along the wall will just cover two headers placed across it with a joint between them. Indian bricks used to be made $12'' \times 6'' \times 3''$ but it was found to be difficult to burn such large bricks thoroughly and the size was, moreover, too large to be handled easily with one hand by bricklayers. They are now usually made $9'' \times 4\frac{3}{8}'' \times 2\frac{3}{4}''$ which admits of their being readily manipulated with one hand leaving the other free for the trowel. Smaller bricks are easier to burn but they take more mortar which is always more expensive than the brick, and they require more labour in setting.

Moulds are made a little larger each way to allow for the shrinkage of the brick in drying and burning. The allowance for contraction is usually one-tenth of the dimensions but the clay should be tested by an experiment to arrive at the exact allowance to be made in each case. Moulds are made without



top or bottom as shown in the figure in the margin. They may be made either of wood or of iron. If of wood, the edges should be protected with brass strips screwed on and only the very best seasoned wood should be used. The long sides project to act as handles for lifting the mould.

To make a brick, the moulder places the mould flat on the ground or on a table, takes a lump of the prepared clay rolled into shape rather longer and thicker than a brick and lifting it over his head with both hands dashes it into the mould with considerable force to fill all the corners as far as possible; he then gives it a few blows with his fist and, if necessary, forces the clay into the corners with his hands. The superfluous earth projecting above the mould is then struck off with a wire on a frame and the mould is lifted off, leaving the made brick on the ground or table. To prevent the clay sticking to it, the mould should be either wetted or sanded for each brick. If water is used for this process the brick is said to be slop-moulded; if sand, sand moulded. The latter should be preferred as it produces a better formed brick with sharp edges.

Bricks are usually made with a *frog* or hollow on the upper surface to provide a key for the mortar joint.

Some of the moulded bricks should be examined by the Engineer occasionally to see that they are being made with well prepared clay. When broken across, the surfaces at the fracture should show no holes or lumps but an even face.

44. When superior bricks are required for brickwork of a high quality or for positions where they will be subjected to more than ordinary pressures, they are pressed in machines after they have been moulded. *Pressed bricks* are made by placing ordinary raw bricks when nearly dry in a metal mould or die and subjecting them to powerful compression under a piston. This is done either in presses worked by hand or in large machines worked by steam power. Such bricks have good smooth faces and sharp edges but they require more care in drying and burning as they are more liable to crack and warp.

45. When a very large number of bricks have to be manufactured quickly at any one place it sometimes pays to mould them in special machines. There are many varieties of moulding machines and a description of even the most common type would be beyond the scope of this manual but they are very similar in design to the machines used for moulding tiles under pressure described in the following Chapter. The clay is first pugged in these machines to reduce it to a thoroughly plastic condition and then forced under pressure through an opening of a size equal to the length and breadth of the bricks in a rectangular plastic band from which bricks of the required thickness are cut off by means of wires fixed in frames. Such machines are very rarely used in India as labour is cheap and plentiful in this country and these machines are expensive in first cost and working charges.

46. The process of *hand moulding* which is the one usually adopted is described fully below.

When a large space of ground is available for the operations, bricks are usually moulded on the ground and left to dry where made. The moulding floors are levelled, rubbed smooth, plastered and sprinkled with sand. The moulder puts his mould down at one corner of the ground and makes a brick there, he then lifts off his mould and replaces it as close as he can to the first brick, makes another alongside the one last made and so on along the top edge of the prepared ground. He then comes back and begins again making a second row below the first and so on till the ground is covered with bricks lying flat and separated by spaces just the thickness of the frame of the mould. The objection to this plan is that however carefully the ground is prepared, the lower side of the brick is apt to be rough and often sticks to the ground.

A better plan is to mould on a slab of wood with a projecting table on the surface ¼ inch deep and the same length and breadth as the inside of mould. The mould itself is in this case made ¼ inch deeper than the thickness of brick required and fits closely round the projection. The edges of the table on the block are protected by brass or iron strips and any *frog* or impression required on the finished brick is arranged for by raised projections on the block which leave corresponding indentations in the face of the brick. The moulder places the mould on the block, dashes in the clay and cuts it off as before described but instead of lifting off the mould, he places a thin pallet board a little larger than the mould flat on top of it and lifts mould, board and brick all together smartly off the block inverting them as he does so. He gives the mould a gentle tap to just loosen the

brick and placing the whole, pallet board downwards, on the table or moulding floor, he lifts off the mould, leaving the brick on the pallet board. A boy then places another pallet on the brick and carries it away between the two boards to the drying ground where he places it on its edge and removes the boards. The next brick moulded is placed close to the first with the thickness of the pallet board between and this is continued till the space is covered. This arrangement differs from the other in that the bricks are laid on edge instead of on the flat; they dry better and more quickly in this position and take up much less space.

A moulder can make six to eight hundred bricks a day. As his labour is skilled and expensive his outturn should be taken as the basis on which the number of assistants required to prepare the earth, carry away the bricks, etc., should be estimated.

47. **Drying.**—The moulded bricks are dried by being first reversed on their edges for a time and then piled in open order in long rows or stacks. The best form of stack is of a breadth equal to two bricks laid longitudinally with intervals between the bricks, the alternate tiers being along and across the stack, all on edge. Eight or ten tiers of bricks on edge with intervals of about 3 feet between them may be thus built up. It is a good plan to make all the stacks the same length and height to facilitate the counting of the number of moulded bricks on the field.

The bricks should be left in stack until thoroughly dry. If they are put into the kilns while still damp, the fierce heat of the kiln is apt to crack and distort them.

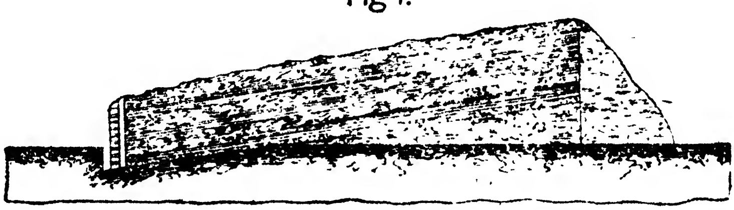
The drying ground should be raised somewhat above the surrounding land and sanded to keep it dry in wet weather. If rain is expected, the brickfield should be furnished with light frames of bamboo and grass or sirki as high as the stack which should be placed on each long-side of the stack on rain coming on and the top should be similarly protected by sirki or matting or bundles of grass. Some heavy boards are usually placed on this temporary covering to weight it and prevent its being disturbed by wind. Brick making is as a rule suspended during the Monsoon rains in India. In the hot dry season, bricks are dry enough for the kiln in three days; in winter, in eight days.

48. **Brickburning.**—This is an operation which requires great care and considerable skill. If the bricks in the body of the kiln are not properly arranged or the firing is not carefully regulated, the bricks near the fire are apt to be overburnt and distorted by the weight of bricks above them, while those furthest from the fire will be underburnt or *pila.*

There are two distinct methods of burning : (1) in a clamp or *pazawah*, (2) in a flame kiln or *bhatta*. In the former the bricks and fuel are placed in alternate layers while in the latter the bricks are stacked without any fuel and burned from fireplaces or flues arranged below the stack in which fires are lighted and kept up with fresh supplies of fuel till the bricks are burned. Clamps have no enclosing walls ; they are merely heaps of alternate layers of bricks and fuel plastered over on the external surface. Kilns are walled structures without a roof, inside which the bricks are arranged.

49. **Pazawahs.**—The ordinary Indian *pazawah* is burned as follows :—A sloping floor is prepared of a quadrilateral shape having two of its sides parallel, the shorter of which is about half as long as the other. The floor slopes upwards from the shorter end about 15 degrees. The short end is in slight excavation, the wide end raised a little above the ground. A layer of fuel consisting of grass, cowdung and litter about 30 inches thick is laid on this floor and covered with four or five courses of bricks set on edge with small spaces between them. A layer of fuel is then laid on about six inches thicker than the layer of bricks ; then another five courses of bricks on edge and so on. When about one-third of the full quantity of bricks to be burnt is loaded, the mass is fired from the short end and goes on burning while the top loading proceeds at the same time. The object of this procedure is to burn the lower part while the upward draught through the intervals between the bricks is still sufficient to keep up the combustion of the fuel. When the firing is completed the clamp is left to burn itself out and cool slowly. If any violent outburst of flame is noticed at any particular spot, it is immediately suppressed by depositing earth or ashes over the spot.

Fig I.



A large *pazawah* containing two or three lakhs of bricks takes about six months to burn and cool. A clamp is therefore not suitable for burning bricks if they are wanted at once. Moreover, as very little regulation of the firing is possible once the clamp is started, the outturn

of the bricks is not uniform, some bricks being overburnt while others are underburnt. A further disadvantage of this system of burning is that as the fuel burns away the whole mass subsides while the bricks are still soft and hot, which often results in a large proportion of the bricks being distorted and cracked.

The advantages of clamp burning are (1) it is economical when the rubbish used as fuel is cheap and available in large quantities, (2) it is a system well understood by native brickburners and (3) owing to the gradual burning and cooling, bricks burnt in a clamp are tougher than those burnt in a flame kiln.

50. **Kiln burning.**—Several descriptions of kilns are used for burning bricks but it is only necessary in this manual to refer to those commonly used by Engineers in India to supply bricks for special works in progress.

The flame kiln has gone through many stages of improvement in India from the Sindh to the Allahabad and finally to the Bull. The Sindh kiln is now practically obsolete and will not be further referred to. In the Allahabad and Bull types, the fireplaces are in the bottom of the kiln and the bricks to be burnt are stacked above these in open order on a fixed plan.

51. The Allahabad kiln is a walled enclosure without a roof 18 feet wide inside, 12 feet high and of a length sufficient to burn the number of bricks required, see Plate 1. Trenches 1 foot deep and 1¼ ft. wide are dug across the floor of the enclosure 4¾ feet apart from centre to centre leaving a space of 3½ feet wide between them, which is called " a rouse." On these " rouses " the bricks to be burned are stacked on edge with slight spaces between them which allow of the passage of flame and heat from the fire in the adjoining flues. The 8th, 9th and 10th courses are corbelled out a quarter brick on each side to meet over the trench and form the flues which contain the fire. Small arched openings are left in the side walls corresponding with these flues and through these the fires are fed and controlled. The fuel used is wood as a rule. A partition wall of bricks laid loosely with spaces between them is roughly built transversely across the middle of the flue to deflect the draught from each side upwards into the body of the kiln.

A low fire is at first started in the arched openings only to dry the bricks thoroughly and after two or three hours the fires are gradually extended into the flues from both ends and kept up vigorously for about three days. Sheet iron plates called " dampers " are suspended over the arched openings for regulating the draught. By raising and lowering

these dampers and by varying the supply of fuel to feed the fires, the heat in the kiln can be regulated to a nicety. The arched openings also act as peep-holes through which the state of the bricks inside can be seen from time to time by the burner to enable him to regulate the feed and draught. When all the bricks are thoroughly burned, all the openings are built up and plastered with clay and the kiln is allowed to cool gradually for about ten days. It is very necessary that the bricks should cool slowly in the kiln before they are withdrawn; if taken out while still hot, a large proportion of them will crack on exposure to the open air. Directly a kiln is unloaded it can be charged and fired again.

There are many points to be attended to in loading and burning to ensure that the distribution of heat will be such that the bricks most distant from the flues are well burned while those forming the flues and immediately above them are not overburned or melted. These however, can only be acquired by experience and cannot be described in detail in this manual.

52. The weak point in a flame kiln of the above description is that as the upper courses of bricks have to be burned a great deal of heat escapes upwards into the air after they have been burned doing no useful work. To overcome this defect, Mr. Bull designed a kiln which utilises this escaping heat to a great extent and thus leads to economy of fuel. This kiln is described below in small type. It is now commonly used in India for burning bricks on a large scale for important Engineering works. It is covered at the top with earth and ashes to prevent escape of heat and the firing is carried on continuously from one end to the other thus forcing the heat to travel horizontally along the length of the kiln instead of vertically through the body of the kiln. The kiln is loaded in sections about 25 feet long with a clear space of six inches between each section over which the draught chimney stacks are fixed. When one section is being burned the heat passes on to the next section and warms the bricks in it before passing out through the chimneys which are kept well in advance of the sections being actually fired. In order to further avoid loss of heat the kiln is usually made circular and in a trench excavated below ground surface. When the first section has been burned and the fire has advanced to the next, all flue holes are closed and the section is left to cool gradually. When the fire is several sections beyond the one first fired and the bricks have cooled sufficiently, the latter is unloaded and loaded again with *kachcha* bricks to be ready for the advancing fire when it has worked round the circle. The kiln is thus

kept burning round and round continuously till the full number of bricks required has been burnt.

Making the kiln in a trench dug out of the ground was a great improvement as it not only saved the expense of constructing side walls but it obviated the trouble caused by the wind, which, blowing as it often does violently from one side of the kiln, makes the regulation of the firing, very difficult. As in this arrangement the ends of a section cannot be got at for feeding the flues with fuel, being down in the ground, small shafts are left at about three feet intervals in setting the bricks above the flues, down which the fuel is dropped.

53. Mr. Bull's detailed description of this kiln is given below—

Bull's Patent Trench Kiln, *[*Plates* II, III.]—The kiln is simply a chamber or excavation dug to the depth shown in *Plate* II, with the bottom sides, and top edges dressed off to a true surface. Of necessity not a single brick need be used in the construction. Doorways, flues, ashpits, openings of any sort and flooring are dispensed with. When excavated and dressed off the proper depth, the sides should be hand-plastered with a mixture of cowdung and mud, as it causes the earth to hold together better.

96. It may be of any width which can be conveniently fired. It may be a short straight piece worked periodically It may be a long straight piece worked semi-continuously, or it may be circular, square, oval or oblong, to work continuously. The process is the same in all, and in different positions each may have its advantages. It will be very easy to adapt the instructions now given to any of the shapes mentioned.

97. The best form of kiln for regularity of outturn is undoubtedly the circular one, but for a small number of bricks it would of course be more economical to construct a straight piece of a length in proportion to the number to be burnt; say up to three lakhs a straight piece, beyond that number circular. Except for the difference of distance from centre to centre of furnaces on the inner and outer faces of a circular kiln, the setting is precisely the same in both. In both cases that distance can be altered at pleasure, there being no fixed conditions of any kind between the kiln and the setting. What may suit one kind of clay may not suit another. When two or more kilns are required in the same brick-field, two straight pieces of 100 feet each, joining to semicircles of the radius given in *Fig.* 1 will give a double kiln, not more than 300 feet being required to work continuously in the present plan. A ring of the mean length of 300 feet would not answer, on account of the great difference from centre to centre of furnaces in such a comparatively small circle.

98. For a long straggling brickfield, one long straight piece would probably be the most suitable. The whole being below the surface of the ground, or only slightly raised, the coolies loading and unloading can walk over and along the kilns at pleasure. Two long straight pieces close together, joined by circular ends with very small radius, are now commonly used.

In the *Plates* (II., III.)—*Fig.* 1, *see Plate* III, is a complete plan of a kiln for working continuously.

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* This description, paras. 95 to 115, is that published by Mr. Bull, and can be obtained separately.

Fig. 2 (top half) is a part plan showing the method of commencing the setting, and the temporary wall for starting the firing.

Fig. 3 (top half) is a part plan showing the top of the setting, and the method of forming the feed-holes.

Fig. 4 is a half plan of two complete chambers covered and ready for firing.

Figs. 5 and 6 give an exact longitudinal sectional elevation of one chimney length, and a portion of another. *Fig.* 6 shows the walls at the feed-hole, and *Fig.* 5 the intermediate walls and chimney space.

Fig. 7 shows a half cross-section between feed-holes.

Fig. 8 shows a half cross-section through feed-holes and furnace.

Fig. 9 shows a templet for giving the position of the bottom brick between each furnace, and the width of the furnaces, in a straight kiln.

Figs. 10, 11, 12 and 13 show the details of the dampers to be used.

Figs. 14, 15 and 16 show the details of the chimneys.

Fig. 17 is a templet for giving the position of the bottom bricks in a circular kiln of the radius shown in *Fig.* 1.

In choosing a site for a kiln, a level piece of ground offers the greatest facilities, but is by no means a necessity, as the sides may be partly raised by mud-wall work or kachcha brickwork. If the excavated earth is good for moulding purposes, it answers best to entirely excavate the kiln, if not I would recommend its being raised 2 feet, and the earth from the remaining depth utilized in levelling off a width parallel to the kiln, and the same height as the top, on which to stack the wood. Two sets of steps, which may be made of mango wood, for the coolies to go up and down on, are required. In all cases there should be a slight fall away from the top edge of the kiln to prevent rain water running in.

A length of 50 feet or more having been excavated, and the bottom and sides treated as directed, loading can be commenced. The width of furnace is 13 inches, and the distance between 2 feet 9 inches. The near wall of the first furnace in each section is only 1 foot 3 inches, and the far wall of the last is 1 foot 6 inches The latter has a greater tendency to settle down owing to the forward action of the flames. Each chimney length or section is exactly the same, and there should be 6 inches between each length to allow in the first place of the dampers being dropped down; and secondly as a smoke chamber over which to place the chimneys. The feed-holes and chimney openings are shown in detail, and should be finished off with a pila brick at the top.

It will be found an advantage to use a moveable sheet-iron chimney as shown in plan, to assist the draught, but if not available, a temporary one can be built up as before mentioned, and need not of necessity be more than 3 feet high.

As each chamber is filled, a compact layer of dry earth or ashes, *never less* than 6 inches in depth, should be evenly spread over the whole, level with the top of the feed-holes. In the cold weather some pila bricks may with advantage be set under the chimneys to catch the steam droppings. It is almost needless to say that the bricks should be as dry as possible. It is not advisable to pack the bricks very tight in the walls, but no actual space need be allowed, except in the three top bricks. Between the bricks of 2nd and 3rd courses half-an-inch space should be allowed, and the top course should be composed of two bricks running longitudinally with 3 inches space between them. The spaces between the walls should never be more or less than 3 inches, and between the outer wall and the face of kiln 4 or 5 inches. If the bricks are larger than shown in the Plate, the width and depth of kiln must be proportionately increased.

Two chimney lengths and part of a third having been set, the temporary cross-wall, with seven short furnaces at the foot of it, should be run up of loose bricks and smeared over with mud; the sheet-iron dampers, *see Figs.* 11, 12, 13, should be put down the second chimney opening, and firing commenced in the temporary cross-wall, shown in *Fig.* 2, before mentioned, slowly to begin with. In putting down the dampers, they simply have to be placed side by side, and the key or intermediate piece pushed down. The crack at the side should be smeared over with a little mud, and also along the top. As steam ceases to rise out of each line of feed-holes successively they should be closed, either with a couple of bricks or a thick square tile, of which a couple of thousand may be moulded specially for this purpose and burnt. Twenty-four hours after firing has commenced, the third chamber should be completely loaded, and the dampers withdrawn from the second opening, and put down the third. The chimneys should be put over the second opening, and the first closed up, as well as all feed-holes. This should be done as tightly as possible to allow of the full power of the chimneys being exerted At the foot of the chimneys 6 or 9 inches of dry earth or ashes should be spread to catch the condensed steam, which principally (but not entirely) runs out through the bottom joint, owing to the peculiar construction of chimneys.

When the heat in the kiln has got up to such an extent that the hand cannot be borne on the chimneys, they should be moved on as before. This rule for moving on the chimney should always hold good, and need not be again mentioned. By this time, if not before, the bricks forming the first furnace will be red hot, and top firing should be commenced from the first row of feed-holes. Three or four hours after a second may be commenced, and similarly a third. This is sufficient for regular working, but until the kiln has been once fired, it may be necessary to continue firing the feed-holes next the wall after the three middle ones have been closed. Cast-iron caps should be provided to cover the mouths of the feed-holes when burning, as anything of earthenware is sure to get broken.

The kiln will now be in full working and the top and bottom firing should be continued, until the first furnace has been sufficiently fired. This can be told by the settlement as well as by the appearance. The bottom firing should be slackened down then, but not discontinued until six furnaces are closed. It should then be stopped, and the furnace mouths loosely closed with bricks, but not plastered. Loading, firing and moving on the chimneys should be going on in proper order, and when 15 furnaces have been closed, more air should be admitted by partly opening the first line of feed-holes. The object of this is to prevent the smoke eddying back along the top of the passages. When 25 are closed, the first now may be opened entirely, and after that every fifth line, beginning with the 25th or 30th behind the firing. Between these and the dampers every feed-hole should be carefully closed, the three rows firing only being uncovered when dropping in the wood or to see how the burning is getting on. The firing is very simple, and any smart coolie can be trained in a week. Just as much wood only as will burn freely without any accumulation of charcoal should be given, one piece generally to each hole about every half hour being sufficient. The system here detailed ensures such a regular distribution, that the utmost perfection of burning is obtained. Except the bottom brick, every individual brick below the brick flat should be thoroughly burnt, and with good clay and care, there need be no overburning. It is obvious that from being able to look down into any part at any time gives complete control over the working. Immediately after moving on the chimneys the draught is rather slack, and the smoke has a tendency to go back to the feed-holes left open to supply air. This must be prevented by firing slowly, and only one line at a time until the draught is well established.

Any sort of tiles that can be set in the walls can be burnt, and with care there need be no loss whatever, either from over—or under—burning. When 40 or 50 furnaces have been closed, the part first fired will be ready to unload. The temporary wall may then be taken down. Four furnaces, equal to 8,000 bricks, may be burnt the first time round, and five the second time, when the kiln is thoroughly dried. The average consumption of fuel should not exceed 4,000 cubic feet of mango or 3,000 cubic feet of bábul, per lakh of bricks 9" × 4½" × 3". The quantity necessary should be stacked concentrically about 2 feet from the inner edge of kiln, and of sufficient width and height for the consumption to keep pace with the burning. When this rule is established it saves all trouble in measurements, and forms an admirable check on the firing. For finishing off at the end of a season, a second temporary wall should be put up 6 inches from the end of a chamber, and the chimneys placed over the space so left. They must not be left there longer than the usual time for moving them, or they will be burnt. They should then be removed as usual, and a short chimney run up of bricks—4 feet high is sufficient.

If a certain proportion of second class is required, the loading may be carried up two bricks higher, taking care to give a little more space between the five top bricks. This is the maximum height that will burn well and economically.

With regard to the apparatus used, the templets shown in *Figs.* 9 and 17 will be found most useful, as giving not only the position of the bottom course, but the width of the furnaces, by making a cut on the wall opposite the forward edge, and then moving the hinder edge up to it. The chimney bench is 6 inches extra. The dampers should have a good coat of tar before use, but not the keys. If the latter get rusty and are stiff to move, a little oil rubbed on them will set them to rights. A set will last for years with care. Four middle and two outer sheets with five keys are required to form a complete damper for the kiln here shown.

The chimneys are shown of the utmost possible length which will permit of their being conveniently moved without being lowered, and if made as in the plan, can be moved on a couple of stout bamboos with the greatest ease. In making them up a theoretically correct section has been sacrificed to simplicity of construction, and very little cutting is necessary. The four sheets to form the upper length having been rivetted together, they can easily be bent over to make a big tube and rivetted. The same with the second length. The short lower length is made by cutting one sheet into four pieces, and acting as with the others. In joining the lengths, the short lower one *must* always be inserted in the next one above it, and if the top edge can be bent in slightly so much the better. The object of this is to arrest all the condensed steam, and allow it to run out on to the layer of dry earth or ashes at the foot of the chimneys, instead of its dropping on to the green bricks and spoiling them. It may even be advisable to rivet a narrow strip inside the middle length of chimney to make sure of this. Two or more good coats of tar should be given to the chimneys, particularly inside and near the bottom. Without this the gases from the fuel, and the moisture together, will eat them away in a surprisingly short time. Before moving they should never be allowed to get too hot to bear the hand on for a moment, or they will be burnt. The distance will vary with the season, from 8 to 15 furnaces from the firing. For the width of kiln shown in the Plate two are required. They should be protected against the action of the wind by stout bamboo struts. The cast-iron caps will be required for three lines of feed-holes with two extra, 17 in all.

To enable the firemen to tell exactly when each furnace has been fired sufficiently, it is an excellent plan to place three bricks in a line across the kiln between each line of feed-holes, say 5 feet apart, level with a brick on each edge of the kiln. A line stretched

across will then tell the sinkage with the utmost exactness. This sinkage will vary with different clays, but generally 2 inches, sinking to 2½ after closing, will ensure a thoroughly burnt outturn. It will very seldom require more than this, but often less.

An estimate of the cost of a kiln similar to the one shown in the Plate is here given:—

	Rs.	a.	p.
Earthwork, 35,000 cubic feet, at Re. 1-8-0	52	8	0
Bricklayers dressing off bottom and sides	24	0	0
Set of chimneys and dampers	110	0	0
Caps (cast-iron)	30	0	0
2 sets of steps of mango wood	6	0	0
1 templet	5	0	0
Contingencies ..	12	8	0
Total ..	240	0	0

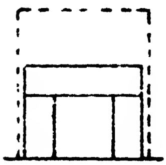
It will be seen that the kiln itself cost only Rs. 76-8-0, or less than one-sixth of the cost of the most economically constructed kiln on the old plan. It is therefore, without exception, the cheapest kiln in existence, it is decidedly the simplest to construct, but even these advantages are subordinate to the fact, that owing to the method of working, not a breath of cold air need ever touch a brick which is likely to be damaged by it, thus ensuring a very high quality as regards soundness, and the maximum of economy, from the utilization of all waste heat.

I think it necessary to state, that the kiln itself, and the combination resulting from the adaptation of the Hoffmann system of top firing with wood to it, and other parts of my original invention, form the subject of separate patents.

Bull's Patent trench kiln *adapted to burning with coal.*—
The great improvement in the draught caused by using an excavated kiln has made it possible to adapt the trench kiln to being fired with coal with a success hitherto unattainable in any kiln fired with that fuel.

A great number of the general remarks in the article describing the trench kiln as fired with wood will apply to the coal firing. The construction is precisely the same, except that it is one brick deeper. The difference in the setting is an adaptation of, but an improvement on, the setting shown in the description of a "Semi-continuous flame kiln for coal" published in the Second Series of the Roorkee "Professional Papers on Indian Engineering" for July, 1875, No. CLXIV. The chimney sections are somewhat shorter than in the wood-fired trench kiln, owing to the distance between the rows of feed-holes being less, the action of the chimneys and dampers is precisely the same, and need not therefore be again described. The coal for top firing should be the usual small coal supplied for brick-burning, but if in pieces larger than a pigeon's egg it should be broken up. Dust coal, with a fair proportion of small pieces, will answer perfectly, but should be fresh. Any attempt to fire with old or dirty coal or cinders will only result in failure. The coal should be stacked for neatness sake, and to save trouble, concentrically, 5 feet broad and 1 foot or more, deep, as may be required, 1 foot inside the inner face of the kiln. Low walls of pila bricks should be run up to hold it. From the length used, it can then be told at a glance if the firemen have been firing too slowly at any time. To save their walking on the kiln unnecessarily, it is advisable to have four earthenwate vessels (*nands*) to hold a maund of coal, placed between the rows of feed holes.

The kiln can be started precisely the same as with the wood firing, or clean rubble coal can be used by making a sort of grate of bricks (*see* figure), the dotted lines showing the furnace mouth in the temporary cross wall. When the bricks as far as the second row of feed-holes are red hot from top to bottom, top firing can be commenced in the first row, and as each row in front gets into a similar state, another can be taken on until five in all are being fired. The ladle for giving the coal with should hold 1¼ lbs. for 9-inch bricks and 1½ lbs. for 10-inch bricks. On starting the firing in each row, six ladles should be given at once to charge the spanners with, afterwards three or four feeds per hour are required. The quantity of coal at each feed being always the same, the firing should be perfectly regular. The setting of the bricks in the combustion chamber distributes the coal with the most perfect and mechanical regularity, and with proper management the burning is in accordance with it.



As coal requires a stronger draught than wood, the firing should be allowed to get a little nearer the chimneys before they are moved on; experience will soon enable an intelligent burner to know to what extent If moved too soon there will be delay it re-establishing the draught, and the smoke will have a tendency to go back for a short time, rendering very slow firing necessary. If allowed to remain too long in the same position, the chimneys pull in cold air with great force from the top where firing, and are also liable to get burnt. The mean between them is what is required. Beyond the difference in the setting and firing noticed, everything else is the same as in the wood-burning kiln.

CHAPTER IV.

TILES, TERRA COTTA, COLOURED BRICKS, GLAZED BRICKS AND EARTHENWARE PIPES.

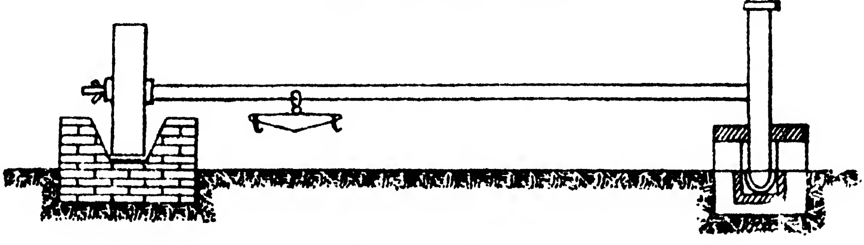
54. Tiles are made in much the same way as bricks but being thin they require greater care in manufacture as they are more liable to crack and warp in drying and burning. The clay should be much stiffer than for bricks, very little sand being used and that only for the very plastic kind. The same previous preparation of the clay is necessary and the more effectually to render it uniform and yielding it is usually crushed and then passed through a pug mill before it is moulded into the shape of the tiles.

55. **Preparation of clay for tiles.**—Plate IV shows the plan and section of a *pug mill.* The clay is put in at the top and water is added as required to moisten it, the mill being kept constantly at work. It is turned by bullocks. The six top knives are four inches wide and bolted into the spindle at an angle of 45 degrees, having teeth let into them at unequal intervals. The seventh bottom knife is six inches wide and let into the spindle at an angle of 55°. The mill is sunk two feet into the ground to allow of convenient filling from above and a ramp is formed to the outlet on one side at the bottom. The outlet is stopped when the earth is first put in until the charge is sufficiently pugged when the tamping is withdrawn and the outlet left open while the mill remains in constant use.

56. For ordinary tiles it is sufficient to pass the clay through a

Fig. 2.

CLAY-CRUSHING ROLLER



crushing mill to grind it to powder, see Fig 2, and then work it up in a pug mill, but for tiles of a superior quality the clay should be dried

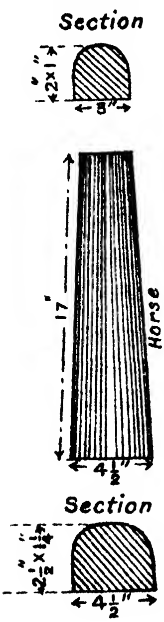
and powdered and then mixed in tanks with a large quantity of water. If well stirred up and then allowed to settle quietly, the coarse heavy particles sink to the bottom and the finer portions are run off in a liquid state from the top into other tanks at a lower level where the water is allowed to evaporate leaving the fine clay ready for the moulds.

57. **Different kinds of tiles.**—Tiles are of three kinds—Floor tiles, Roof tiles and Drain tiles. Floor tiles are flat and usually 12" square and 1" to 1½" thick if intended for ordinary floors, but much smaller and of different shapes if *encuastic* or coloured to form patterns of different colours. Roof tiles may be flat like slates or shaped to different patterns such as semi-circular pantiles, Allahabad tiles, corrugated tiles, etc. Drain tiles are usually long tiles of curved section and of various shapes and sizes to suit the work for which they are intended.

58. **Moulding.**—There are three methods usually adopted in India for moulding tiles,(1) moulding them flat in the first instance, and then shaping them to the required curvature on wooden patterns, (2) forcing the clay under pressure by mechanical means through an orifice, (3) if perfectly circular in section by turning them on a potter's wheel.

For tiles which are not uniform in section throughout their entire length, the clay must be moulded on patterns—a flat tile is first moulded and when partly dry it is closely pressed round a wooden pattern to give it the required shape.

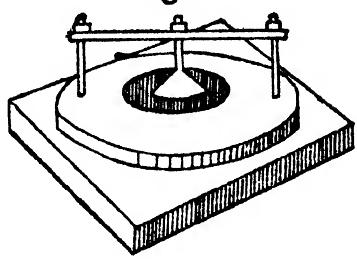
Fig. 3.



The second process is adopted when the section is the same throughout its entire length. The prepared clay is put into a closed box and covered by a piston moving inside the box to which considerable pressure is applied by mechanical means. Under this pressure the clay is forced out of an opening in the bottom or one side of the box which opening is of the section required for the article. The clay issues in a long mass and is cut off by wire frames to the required lengths. If the orifice is rectangular, the articles thus moulded would be bricks or flat tiles; if circular, with

an internal solid central core leaving an annular space all round, as in Fig. 4, the section obtained would be tubular, and so forth. The clay as it passes out of the orifice is received on a moving platform which in the case of bricks or flat tiles [issuing through a side of the box] consists of a series of small rollers in a horizontal frame and in the case of tiles of circular or other section of a scale pan under the box, balanced by weights, which moves up as each length is cut off and removed to make room for the next as it issues.

Fig. 4.

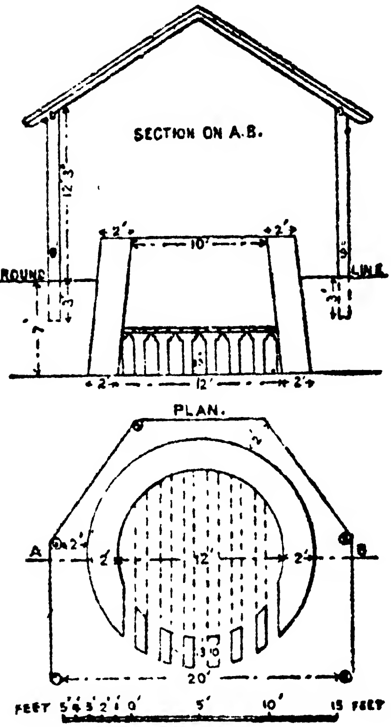


The third process can only be applied to patterns, each horizontal section of which when on the wheel is a complete circle, though the diameter of the circles may vary to any required extent along the length. The potters' wheel is a heavy solid circular table or disc revolving horizontally on a vertical spindle which works in a socket in the ground. The potter takes a short stout rod and placing one end on the wheel a short distance from the centre, turns the wheel round quickly by repeated pushes till it acquires a considerable velocity and spins by itself. He then takes a lump of prepared clay and places it round the centre of the wheel. As it spins round he fashions it roughly to shape vertically either with his hands or by a wooden pattern. Indian students are no doubt familiar with the operations of the "koomhar" making "gharras" and other earthenware vessels and will therefore readily follow the above description. With some improvements by which the motion of the revolving table could be made continuous and by the use of suitable patterns, good work could no doubt be turned out by this means.

59. **Burning.**—The burning of tiles has to be done more gradually than for bricks to prevent warping. Where bricks and tiles are being made at the same time, the upper part of the kiln is reserved for the tiles, as being thinner they require less heat. The tiles are always placed on their edges two or three courses deep. They should not be piled up in many courses as being delicate they are apt to crush and become distorted under pressure. When they are not made in conjunction with bricks and have to be specially manufactured they are burnt with great care in ordinary flame kilns with permanent corbelled flues in

the lower part of the kiln, see Fig 5. In setting the kiln, a flooring is first made by a course of bricks laid flat and somewhat open over the tops of the flues and on this flooring the tiles are stacked as closely as they will lie on edge, course on course. The burning is effected usually with wood. As in the case of bricks, the fires must be low at first until the disappearance of all white steam; they are then raised gradually till the inside of the flues appear red hot; the firing is then slackened for six hours and again raised till the interior of the flues has been brought to a white heat at which they are kept for about three hours. The fire is again slackened for six hours and the same process repeated after which the flues are filled up with fuel and their mouths stopped up with brick and mud, the fires being allowed to die out gradually. The operation generally takes seventy-two hours, being maintained night and day. In windy weather, the kiln should be sheltered as far as possible on the weather side. If this is not done a large number of tiles on that side will probably be found underburnt.

Fig. 5.



60. **Terra cotta.**—This is a superior description of earthenware, prepared and burned in much the same way as bricks or tiles but with greater care and nicety both as regards the selection and preparation of the clays used and also in the operation of burning. It is largely used in England for encaustic floor tiles and for ornamental work of various kinds, such as cornice mouldings, vases, statuary, etc.

Terra cotta always contains a certain proportion of ground glass or pottery ware or both to reduce shrinkage in burning and to make it very hard and durable and impervious to moisture. The pottery ware used is not crushed to a very fine powder but is reduced rather to a gritty state; the glass on the other hand is reduced to a fine powder. The usual proportions of the materials forming the mixture are 8 parts

sifted dry clay, 3 parts crushed pottery, 1 part ground glass and 2 parts clean white sand.

The clay is sifted in a dry state and mixed in tubs with a large quantity of water to which is then added the glass, pottery and sand, the whole being vigorously worked up with spades or similar tools to produce an intimate mixture of all the materials. It is then lifted out and placed in large wooden boxes with joints sufficiently open to allow the water to run off. When it is thoroughly drained and dry enough for the pug mill, it is passed through it *several times* and is then fit for moulding.

The burning of terra cotta has to be managed with great care in every respect but there is one peculiarity in the operation without which the uniformity of colour required cannot be attained. The articles are completely enclosed in an inner casing of fire brick or *muffle* as it is called, and the fire is not allowed to come in close contact with them in any way. The muffle is built inside the kiln with an air space all round between it and the walls of the kiln. See plate V.

61. **Coloured bricks.**—There are two methods in use for colouring bricks; one, by mixing certain colouring matters with the clay before burning and the other by dipping the brick in a colouring liquid after it has been burnt. The first method may be adopted when the colouring matter is cheap and available in sufficient quantity. The second is suitable for expensive colours and admits of a great variety of colours being produced at comparatively small cost and with little risk of failure or trouble.

The colouring materials used for the first method are of the ordinary kind, e.g., yellow ochre, red ochre, red brick or soorkhee, manganese, ultramarine, etc.

62. The second method of *colouring by dipping* is a very simple process and bricks or tiles coloured in this way will stand any amount of exposure to weather without losing their colour. The materials used for the colouring liquid are turpentine, linseed oil and litharge with colouring matter as may be required. The bricks or tiles are first heated by being placed on an iron plate above a fire. They should not be heated to a great heat but to such an extent that they are too hot to handle. They are then taken one at a time and dipped into the liquid for a few seconds, then placed on a table to dry. When dry they are washed clean with the hand or a rag in a trough of cold water. This completes the operation.

63. **Glazed bricks and tiles.**—It is sometimes advisable to glaze the surfaces of bricks or tiles or earthenware pipes to protect them from the

action of the atmosphere, sewage or other destructive agents. This is usually done by throwing salt into the furnace when the articles it contains are at a high temperature. The heat of the fire volatilises the salt (chloride of sodium) The chloride escapes while the sodium combines with the silica, alumina, lime or iron in the clay to form a surface coating of glass which penetrates every pore and crevice in the material and is very durable.

64. **Earthenware pipes.**—These are made from ordinary clays similar to those used for common tiles. The clay is finely ground, sifted, washed, pugged and then forced by machinery under pressure through a mould in the manner described above for tiles. They are also dried and baked in the same way as tiles. Such pipes of a cylindrical shape and without sockets are used to a large extent for colaba outlets by the Irrigation branch of the Public Works department. When used for sewage they should be glazed to protect them from the destructive effect of acids. The different shapes of ordinary and special socket pipes and their accessories for sanitary works are shown in the figures on Plate VI. Sewer pipes should be up to the following specification. They should be of sufficient strength and toughness to resist fracture under the earth pressure and shocks to which they are likely to be subjected, hard, homogeneous, impervious, uniform in thickness, true in section, perfectly straight longitudinally or formed to the required curve, uniformly glazed both inside and outside, free from fire cracks and flaws of all kinds. They should ring clearly when struck.

CHAPTER V.

LIME, CEMENT, MORTAR, CONCRETE, AND PLASTER.

65. Mortar is used to bind together the stones or bricks of the walls of a structure, or as plaster to provide a smooth hard surface. In India, for temporary work and inner walls, mud mortar made of carefully prepared brick earth, or "*gara,*" is frequently used for economy. It has of course little or no cohesion, but the only strain walls have to bear in most buildings is vertical pressure, and mud mortar hardens sufficiently to bear this for ordinary heights while it serves to give the bricks or stones an even and firm bearing on each other. Brickwork, or stone masonry in good mud mortar carefully prepared, may be assumed to stand safely a pressure of 1½ tons per square foot. For permanent structures of importance or walls exposed to the action of water, lime mortar is of course an absolute necessity.

66. What is required for mortar is obviously some substance that will harden and adhere strongly to brick or stone shortly after it has been used in a soft state, for putting these materials together in a structure. Now lime, which is the chief ingredient in all mortars has this peculiar property. When powdered and mixed with water it makes a soft paste which absorbs carbonic acid gradually from the air and hardens after a short time into a solid compact body.

67. **Lime.**—Limestone in its natural state is calcium carbonate ($Ca\,CO_3$) mixed with more or less earthy matter. Marble and chalk which are its purest forms contain little else but calcium carbonate and are white in colour, but when the stone is impure it contains a mixture in varying proportions of sand, clay, magnesia, and oxide of iron, and in this state it is found in various colours as white, cream, blue or grey. It is also of various textures as crystalline, granular, compact, and earthy.

When limestone is subjected to considerable heat, or *calcined,* the carbonic acid (CO_2) of the calcium carbonate is driven off into the air leaving only calcium oxide (CaO) which is called *quicklime.* If water be added to quicklime it "slakes," i.e., it absorbs the water with effervescence and swells, giving out heat, and if in the form of lumps, falls into a fine powder. It has now become calcium hydrate $Ca\,(HO)_2$ generally known as "slaked lime." This action is represented by the equation.

$$CaO+H_2O=Ca\,(HO)_2$$

If the limestone is pure calcium carbonate the "slaked lime" is two or two and a half times the volume of the *quicklime* from which it

is produced. This increase in bulk is not so great in limestones containing a mixture of sand, clay, magnesia or iron. There is little or no change in volume in limes containing a large admixture of these substances and the slaking action is very mild.

If "slaked lime" is mixed with sufficient water to make it into a paste and left exposed to the air it slowly hardens or *sets.* This property of *setting* is not well understood by scientists but it may be generally ascribed partly to drying and partly to the absorption of carbonic acid from the air which reconverts it into calcium carbonate.

It is found, however, that mortar made of pure slaked lime, known as *rich lime*, will not set throughout. It hardens on the surface in course of time but if used in bulk or in thick joints it will remain soft under the hardened skin and have no cementing value. In thin joints and under heavy pressure it sets slightly, but even under such conditions it is not *satisfactory* as a cementing material.

If the pure lime is mixed with some inert substance such as sand the setting action is improved but not to any considerable extent. It is rendered more pervious to the air so that the hard skin is deeper but the mortar thus made is still not a satisfactory cementing material. It sets very slowly in air and will not set at all under water. A natural lime containing sand only as an adulterant is known as a *poor lime.*

Other impurities, however, notably clay, and, to a lesser extent, magnesia and oxide of iron effect a considerable improvement in the setting properties of the lime. A mechanical mixture of lime and burnt clay in fine powder gives good results in this respect, and a mortar made of these materials will set satisfactorily both under water and in the air; but if clay, magnesia and iron are found mixed in the natural limestone before it is burnt the lime produced therefrom will set much more rapidly and acquire greater strength in a short time. Such lime is called *hydraulic lime* from its quality of setting even better under water than in the air. A lime is said to be "feebly hydraulic" if it contains 5 to 12 per cent. of clay associated with carbonate of lime or with carbonate of lime and carbonate of magnesia; "ordinary hydraulic" if it contains 15 to 20 per cent. of clay, and "eminently hydraulic" if it contains 20 to 30 per cent.

Feebly hydraulic lime slakes a few minutes after water is sprinkled over it, with development of heat, cracking, and ebullition of vapour. In setting under water it is firm in 15 to 20 days and as hard as soap in 12 months.

"Ordinary hydraulic" lime shows no sign of slaking for an hour or two, and finally cracks all over with slight fumes and development of heat. In setting under water, it resists the pressure of the finger in a week and in 12 months it is as hard as soft stone.

"Eminently hydraulic" lime is very difficult to slake. Slaking commences after long and uncertain periods subsequent to wetting. The development of heat is very slight and sensible only to the touch. There is often no cracking and no powder is produced. In setting under water it is firm in a day, hard in 3 or 4 days, very hard in a month and in 6 months it can be worked like a hard limestone.

Artificial hydraulic lime may be made by moderately burning an intimate mixture of rich lime with as much clay as will give the mixture a composition similar to that of a good natural hydraulic limestone. If a soft material such as chalk is used, it may be ground and mixed with clay in the raw state, but if compact limestone is used it is usually first burnt and slaked, then mixed with the clay and burnt a second time. Lime treated by the latter method is called "twice kilned lime."

The most common natural hydraulic limestone found in the plains of Upper India is "kankar." This contains as a rule from 8 to 30 per cent. of clay and makes excellent hydraulic mortar. But some varieties contain a large proportion of sand and other impurities and are not worth burning for lime. It is advisable therefore to make careful tests before accepting this material for lime manufacture. It is further necessary to see that if burnt in clamps, the fuel used is coal or charcoal which gives little or no ash. If cowdung and litter are used, a large quantity of ash is liable to get mixed with the burnt lime and reduce its strength considerably.

68. **Cement.** *Cement* is similar in many respects to the best hydraulic lime but it possesses hydraulic properties to a far greater degree and does not slake or break up when wetted after being burnt. It is used for wet foundations and sub-aqueous work of all kinds, for important structures of great strength, for watertight walls, and floors of reservoirs and channels, for superior pointing or plaster and many minor purposes. It usually contains 30 to 50 per cent. of clay.

Cements may be divided into two classes (1) Natural, (2) Artificial.

69. **Natural cements** are burnt direct from stones containing 30 to 40 per cent. of clay, the remainder being carbonate of lime or carbonate of lime mixed with carbonate of magnesia. The best known natural cement in England is that which is termed "Roman." The stone is

found in nodules in the London clay. Before calcination it is of a fine close grain and has rather a pasty appearance, the surfaces of fracture being greasy to the touch. It is of a grayish white colour. When burnt, the stone loses about one-third of its weight and becomes brown. It is usually burnt in conical kilns to an extent sufficient to drive off the carbonate acid. The burnt stone is pulverised and stored for sale in well closed casks. It is very quick setting but not so strong as Portland cement. In India, cement stone is very rare so an artificial substitute is commonly used.

70. **Portland cement.**—The best known *artificial cement* in England is "*Portland cement.*" This is imported in large quantities for use in India. It consists of 8 or 9 parts of chalk mixed with two parts of mud containing about 70 per cent. alumina and 30 per cent. silica. The chalk and mud are both obtained from the river Medway. The ingredients are passed through a crushing mill and carried off by water into large shallow vats. The sediment deposited is dried in an oven, and then burned in a kiln with alternate layers of coke, at a very high temperature, until it is in a state of incipient vitrifaction. This excessive burning is the distinctive feature of its manufacture. It is then crushed between two iron rollers, ground and carefully packed in casks. Before packing, the ground cement is spread out and allowed to cool for some days on a dry floor as this "air slaking" (perhaps by killing any particles of pure lime which remain in an active state) is found to be most beneficial. If this is not done, the cement is apt to swell after use as mortar and injure the work to which it is applied. Portland cement is admirably suited for structures exposed to the action of water, and for external plaster, as it sets very hard and remains free from vegetable growth which natural cements do not. It sets harder under still water than it does in air. If used for subaqueous work it has to be protected at first from currents but in two days it sets hard enough to withstand any current. It *begins* to set at once after it is mixed with water, so it should always be used as soon as possible after it has been made into a paste for use as mortar. Its tensile strength is 350 lbs. to 450 lbs. per square inch after one week's immersion in water.

The process described above is that adopted on the Thames and Medway where the manufacture of Portland cement was first started many years ago. In very modern works at other places certain modifications have been introduced which cannot be entered into in this Manual. In some parts of England the denser limestones are now used in the absence

of chalk, for the manufacture of Portland cement, and shales are often used instead of clay.

Students requiring further information on this subject will find useful particulars in " A Practical Treatise on the Manufacture of Portland Cement," by Reid, or in "The Practical Manufacture of Portland Cement," translated from Lipowitz.

Limestone and clay suitable for manufacture of cement are very rare in India and this material has therefore not been manufactured locally to any great extent. Kankar yields very good mortar for ordinary hydraulic works, and for special jobs English Portland Cement is commonly used. Madras and Calcutta cements have lately come into the market, but so far there has been no great demand for them in Upper India as far as the author is aware.

A specification of Portland cement issued by the British Engineering Standards Committee which is now commonly adopted by engineers in England for important works is given in Appendix A.

71. **Lime burning.**—Like bricks, lime is burnt in a clamp or a kiln.

72. For burning lime in quantities so small that they would not repay the cost of a permanent kiln, a clamp is most suitable. It is commonly adopted by Indian brick burners in all parts of the country and kilns are seldom used by them. A clamp is formed as follows :—

A circular space is cleared on the ground, say 16 feet diameter and the broken limestone and fuel are laid on it in alternate layers if wood is used, or, well mixed together if charcoal is used. A heap about 12 feet high is thus made with slightly sloping sides and plastered over with mud. It is fired from the bottom in much the same way as a "pazawa" described in the chapter on bricks.

The objection to a clamp is that there is considerable loss of heat and waste of fuel, and the lime partially powdered in the actual burning is apt to get mixed with the fuel ash from which it cannot be separated. If coal or charcoal is used the latter objection does not apply to any appreciable extent as these fuels give very little ash.

73. When a large quantity of lime is required for large works it is better to construct a circular enclosing wall within which the burning can be carried on. In a *perpetual kiln* of this description (See Plate VII) the burned lime is drawn out from the bottom through small arches in the enclosing wall and fresh charges of limestone and fuel are added at the same time at the top. Perpetual working is thus secured which results in much saving of time and fuel, as the kiln does not cool

down in the intervals between two charges as it must do in the case of intermittent kilns.

74. **Intermittent kilns.**—The limestone charge is laid in a heap on the fuel which is either burnt in arched flues at the bottom as in brick flame kilns or in a stack on the floor of the kiln. The Dehra Dun kiln shown in Plate VIII is a good example of the latter method of burning.

Wood is generally used for intermittent kilns while coal or charcoal is more suitable for perpetual kilns.

75. The following figures may be taken as a rough guide for estimating the consumption of fuel in burning ordinary limestone and the approximate volume and weight of the outturn.

Ten maunds of coal or 32 maunds of fairly dry wood to every hundred cubic feet of limestone lumps put into the kiln—outturn 80 cubic feet of burnt limestone or about 40 maunds (1 maund=80 lbs.). In slaking, the volume of burnt limestone is increased to about double if the stone is pure, or nearly pure, carbonate of lime. The larger the proportion of clay the less is the increase of volume in slaking. A cubic foot of pure white lime weighs 23 seers or about 46 lbs. A cubic foot of hydraulic lime may vary from 50 to 70 lbs. according to the proportion of clay in it.

76. **Slaking and grinding.**—Pure burnt limestone slakes, that is falls to powder, at once when sprinkled freely with water, and is then ready for mixing with other ingredients to make mortar, but impure or hydraulic limes often do not slake at all and have to be ground to powder after burning before they can be used for mortar. When the quantity is small, the pulverizing may be done by hand with heavy wooden beaters, but when a large quantity has to be dealt with a mill with stone or iron rollers, usually worked by bullocks or steam power, is usually employed. A machine called a *disintegrator* is sometimes used for this purpose. This consists of a circular iron case having a central axle set with steel arms which is revolved by an Engine and gearing at a great velocity and beats the lime to fine powder; this falls out through fine gratings in one side of the case.

All lime should be slaked or pulverised at or near the work if possible and used up shortly after burning, as slaked lime absorbs carbonic acid and moisture and begins to set if kept stored for a long time.

77. **Lime analysis.**—As the thorough analysis of a kankar or limestone is an operation which few Engineers can perform for themselves, the following approximation is often useful. Pound a sample in a

mortar and pass it through a fine sieve; put 150 grains in a tumbler and pour gradually on it diluted hydrochloric acid, stirring it with a bit of wood. Add the acid until effervescence ceases, then filter through blotting paper and wash by pouring fully a quart of water through the filter The residue is clay or sand or both. It should be carefully dried, collected and weighed. The difference between this weight and the 150 grains represents *carbonate of lime*. The residue should now be repeatedly washed by decantation to get rid of the lighter particles of clay until sand alone is left which should be dried and weighed. If the 150 grains are found to contain 110 grains carbonate of lime 10 grains clay, and 30 grains sand, the stone should furnish a fair lime for general purposes. With smaller proportions of clay the setting properties will be poor and the cementing quality of the lime will therefore be inferior.

Another simple plan which may be employed is to weigh a piece of the stone after it has been thoroughly dried; then heat it to redness in an open fire for about 4 hours to expel the carbonic acid; allow the stone to cool and again weigh it. The loss of weight will show the carbonic acid from which can be calculated the amount of lime, as in every 100 parts of carbonate of lime are 56 parts of lime and 44 parts of carbonic acid.

78. If, however, the Engineer's opportunities and appliances allow of a *thorough* analysis, it should always be made. The following directions drawn up by the late Dr. Murray Thomson*, may be used for mortar as well as a limestone.

1. **Selection of the sample.**—Care should be taken to get a fair average sample. In the case of a mortar a handful from various parts of the heap should be taken, and these thoroughly mixed; about two ounces of this should then be put in a well closed bottle. In the case of a limestone or kankar, pieces should be broken off from various parts of the mass, or if it exist in several pieces, then parts of each should be taken.

2. **Preparation of the sample for analysis.**—The sample should now be reduced to powder, first in an iron, and then in an agate mortar. The powder should be so fine, that no grit whatever can be perceived when a little of it is rubbed between the fingers. From 5 to 6 grammes of the sample should be thus pulverised, and kept in a stoppered bottle labelled with a label corresponding to that of the sample.

3. **Estimation of the water.**—It will be sufficient to dry about one and a half grammes, at 100C until it ceases to lose weight, and the loss entered in the analysis as "water." For a more accurate process for estimating water in a limestone, as well as for fuller details on the analytical process generally, reference is made to "Quantitative Analysis by Fresenius" (3rd Edition, page 553).

4 **Estimation of the siliceous residue.**—About two grammes† of the sample are put in a beaker glass, and covered with half an inch of distilled water; the beaker is now inclined to an angle of 60°, and some pure hydrochloric acid is added. The inclination

* M.D., F.R.S.E., Professor of Experimental Science at the Thomson Civil Engineering, Roorkee, and Chemical Examiner to the Government, N. W. Provinces.

† All weights taken must be made accurately with a balance which will turn easily with a miligramme, when the scales are loaded with 50 grammes each.

of the beaker is to prevent loss by spirting during the effervescence. When the effervescence has ceased, a little more acid is added, and the whole is then slowly evaporated to dryness. The last part of the evaporation must be done in an air bath. As soon as the mixture is quite dry, about half an ounce more of distilled water must be added a long with a few drops of hydrochloric acid, the mixture made warm and filtered; what insoluble matter remains on the filter is now thoroughly washed with hot distilled water, the washings being allowed to fall into the first filtrate. The residue on the filter should be washed until a drop of the washings leaves no residue when evaporated on a bit of platinum foil. The insoluble residue on filter is treated as para. 9 directs.

5. **Estimation of the Oxide of Iron, Alumina, etc.**—The acid filtrate and washings are now heated to boiling, and strong liquor ammonia cautiously added, until after the last addition the mixture smells distinctly of ammonia. A brownish red precipitate will have fallen by this treatment; this precipitate is now to be collected on a filter, and rapidly washed with boiling distilled water. The precipitate on the filter is to be treated as para. 11 directs.

6. **Estimation of the Lime and Magnesia.**—The filtrate and washings from the last operation are now well mixed and divided into two equal parts, which may be called A and B. In A the lime, and in B the magnesia is estimated.

7. Portion A is now heated to boiling, and while in ebullition 20 cubic centimeters of a standard solution of oxalic acid are added*, care should be taken that the mixture is still alkaline after the addition of the oxalic acid; if necessary, a few drops more ammonia should be added. The precipitate of lime oxalate which has been produced is now separated by filtation, and the precipitate is washed by boiling water 3 or 4 times. The filtrate is now warmed to 60 C., 2 C.C.† of oil of vitriol are added, and a standard solution of permanganate of potassium gradually dropped in, until its colour remains permanent.

The process just described is a very rapid and very correct one for the estimation of lime, and where many limestones or mortars have to be analysed it is well worth while to prepare and keep ready a small stock of the two standard solutions required. The preparation of the permanganate solution is described below.‡ The process may be explained thus; enough of the oxalic acid solution is added to precipitate all the lime, and leave an excess of itself in the filtrate. The amount of this excess of oxalic acid is then determined by the standard permanganate solution, which decomposes the oxalic acid in the presence of sulphuric acid, and at a certain temperature into carbonic acid, thus:—

Permanganate.	Oxalic acid.		Sulphuric acid.
$K_2 Mn O_8$ +	$5 (C_2H_2O_4)$ +		$4 H_2 SO_4$
$2Mn SO_4$ +	$2 KHSO_4$ +	$8 H_2 O$ +	$10 CO_2$
Sulphate of manganese.	Sulphate of potassium.	Water.	Carbonic acid.

While this action is going on, the fine purple colour of the permanganate disappears, but as soon as it is completed, the colour of the permanganate remains. The amount of

* This standard solution of oxalic acid is made by dissolving 31·5 grammes of ordinary crystalised oxalic acid in a litre of distilled water. A label should be affixed to this solution, to the effect that each cubic cent. contains 0315 of a gramme of oxalic acid, and corresponds to ·014 of lime.

† C. C. Means cubic centimetre.

‡ 10 grammes of crystals of permanganate should be dissolved in a litre of distilled water. This solution should then be titrated by the standard solution of oxalic acid, so that 10 C.C. of the permanganate will equal 1 C.C. of the acid.

solution of permanganate used to produce this permanent colour is then read off, and every 10 C.C. of it correspond to 10.C. of oxalic acid solution. All that is necessary to complete the estimation of the lime is, from the permanganate used, to calculate the oxalic acid in the filtrate: this oxalic acid is over and above what was required to precipitate the lime, and if now it be deducted from the 20 C.C. used, the remainder has to be calculated out as lime, at the rate of 1 C.C. of oxalic acid solution, corresponding to ·0112 of a gramme of lime. The result should be multiplied by 2, as only half the filtrate was used.

The only trouble about this process is the preliminary one of preparing the standard solution of permanganate and oxalic acid, but once these are prepared the estimation of the lime is easy and rapid, and that cannot be said of any other method of estimating lime.

8. Portion B is now to be employed for the estimation of the magnesia: for that purpose it is heated to boiling, and oxalate of ammonium is added in slight excess. The mixture is then allowed to stand 12 hours: at the end of this time the precipitate of oxalate of calcium will have completely subsided. Now the clear fluid is separated by decantation, and the precipitate collected on a filter, and washed with cold water. The washings and decanted fluid are now mixed, and ammonia added until the solution smells of it; and then solution of phosphate of sodium; the whole is then well stirred. If the stirring is kept up for 15 or 20 minutes, the whole of the magnesia will be thrown down as magnesium and ammonium phosphate, which may be at once collected on a filter and washed with cold water, having about $\frac{1}{10}$ of solution of ammonia added.

9. The insoluble residue obtained by process in paragraph 4, is now, having been dried, incinerated along with the filter and weighed; a certain amount is deducted for filter ash; this amount is ascertained by incinerating 10 filters, and dividing the ash obtained by 10. The weight of the residue is now calculated as a percentage result, and entered in the analysis as residue insoluble in hydrochloric acid or simply siliceous residue. It contains any sand, clay, and organic matter which may be in the sample.

10. In the case of a hydraulic limestone, the clay in this insoluble residue ought to be estimated: for this purpose, it should be thrown little by little into a boiling solution of carbonate of soda (best boiled in a silver vessel). The pure silica or sand will be thus dissolved, and the clay left insoluble; it is only needful to ascertain the weight of the latter after thorough washing, drying and incineration.

11. The precipitate of oxide of iron and alumina obtained in paragraph 5, is now incinerated and weighed, and (after deduction for filter ash) calculated as a percentage, and entered in the analysis as oxide of iron, and alumina dissolved by hydrochloric acid.

12. The precipitate of magnesia and ammonium phosphate obtained by paragraph 8, is also dried, incinerated and weighed, and the amount multiplied by 2, as only half the filtrate was used (it should be well dried before incineration), filter ash being deducted. Every 222 parts of the substance weighed contains 80 of magnesia, its composition being the magnesium pyrophosphate $Mg_2 P_2 O_7$.

13 **Estimation of carbonic acid.**—In the case of a limestone, it is not needful to estimate the carbonic acid, as all the lime, and all the magnesia obtained in the analysis may be calculated as carbonates and entered in the analysis as such. Every 56 of lime, and every 40 of magnesia require each 44 of carbonic acid. In the case of a mortar the carbonic acid must be determined, as part of the lime exists as hydrate and part as carbonate. About 3 grammes of the finely pounded mortar are put in a small flask fitted with a chloride of calcium tube, and a very small test tube; in the latter is put some

strong hydrochloric acid. The mortar at bottom of flask is covered with distilled water, the small test tube full of acid is lowered in by means of a piece of fine platinum wire, so as to remain upright, and allow no part of its contents to be spilled. The chloride of calcium tube fitted to a cork with a small draught tube, is then adjusted to the mouth of the flask, and the whole is weighed. Then the flask is inclined so as to spill the hydrochloric acid among the water and mortar (the acid should only be spilled over gradually); a brisk effervescence ensues from the escape of the carbonic acid; when all the acid has been spilled over, and effervescence has quite ceased, a gentle draught of air is drawn through the apparatus by the mouth; the apparatus being now weighed, it will weigh less; the loss shows the amount of carbonic acid.

79. **Practical rough tests of the quality of a hydraulic limestone.**—The colour should be bluish grey or brown, as white indicates pure limestone or gypsum. It should only partially dissolve in diluted hydrochloric acid, leaving a more copious residue than pure limestone. If these tests are satisfactory break a sample into fragments not exceeding 1½″ in size and put a few pieces into an ordinary fire place for about 3 hours. Take out one piece and immerse it in a glass of diluted hydrochloric acid. If the stone is just sufficiently calcined no effervescence should now take place nor should the colour become darker. Having obtained a piece properly calcined reduce it to powder and mix the powder with about one-third its volume of water to make it into a paste of moderate consistence. Knead the paste into a rough ball between the hands. It will soon become warm and if it be a good hydraulic lime it will not only harden in the heating but if put into a basin of water it will continue hard and go on hardening. It is better not to put it into water until it has begun to cool a little.

80. **Strength of limes, cements and mortars.**—The adhesive and tensile strength of limes and the mortars prepared from them is tested in the following manner:

To ascertain the adhesive strength, two bricks, say 10″×5″, are crossed and cemented together by the sample to be tested. This will give a sectional area for test of 5″×5″ and projections of 2½″ on each side. The projections are used for suspending the upper brick from a frame or overhead support and for hanging from the ends of the lower brick a board which carries the test load. Weights are gradually added to the load on the hanging board till the joint gives way. The breaking load divided by 25 (5×5) gives the ultimate adhesive strength of the sample per square inch.

To test the tensile or cohesive strength, briquettes of the sample moulded to the shape shown on the margin are carefully prepared and

broken in a machine specially designed for the purpose. There are many

patterns of testing machines all worked on more or less the same principle. The lower briquette clamp is usually fixed to the base of the machine and the other is pulled upwards by a lever actuated by hand gearing or by weights, the force exerted at the breaking point being indicated on a dial or a graduated scale. The student will see one of these machines in the College Laboratory where he can examine the details of its construction.

81. **Mortar.**—This consists of a mixture of lime or cement with sand or surkhi (burnt clay) in different proportions, to form a paste for use in masonry, brickwork and concrete or for plaster and pointing. In masonry or brickwork it is used to bind together the bricks or stones, to give them an even bed which prevents their inequalities from bearing upon one another and thus to cause an equal distribution of pressure over the beds. In concrete it is used as a matrix for broken stones or bricks to combine them into one solid mass. In plaster and pointing it is used to protect the joints and exterior surfaces of brickwork or masonry from the disintegrating effects of the weather and to give the work a smooth pleasing appearance.

82. As above explained rich or fat lime mixed with sand makes a mortar which is of little value for building purposes as it does not set hard and has no hydraulic properties. It is practically useless for works of any importance. Poor limes may be placed in the same category and feebly hydraulic limes mixed with sand are not much better. Hydraulic lime or cement mixed with sand makes a good mortar, but sand in this case plays no part in imparting strength, hardness or hydraulicity to the mortar produced from it. It merely acts as an adulterant and is used to save expense and prevent excessive shrinkage on drying. For ordinary work, neat hydraulic lime or cement would as a rule be too strong and it is therefore economical to add as much sand as possible without reducing the strength of the mortar below what is actually required. With hydraulic lime such as that ordinarily made from good kankar, 1 lime to 1 sand makes a strong mortar, while 1 lime to 1½ or 2 of sand gives a mortar of sufficient strength for works of minor importance especially if the lime is of superior quality. For works of special import ance where great strength is required or hydraulicity is the main object

such lime would be used without any admixture of sand. With Portland cement 1 cement to 2 sand makes a very strong mortar, and 1 cement to 4 or 5 sand a mortar of sufficient strength for ordinary purposes.

83. Fat or feebly hydraulic limes mixed with powdered burnt clay *(surkhi)* produce a very fair mortar which exhibits considerable strength and distinct hydraulic properties if carefully prepared. The burnt clay should be pulverised to a very fine powder if good results are required, and the mixing should be thoroughly well done in a mortar mill to bring the particles of lime and clay into close contact and to make an intimate mixture. The proportion of lime to surkhi is usually 1 to 1½ for ordinary mortars and 1 to 2 for works of minor importance. If good coarse sand is available at small cost, the mortar is sometimes made of 1 lime, 1 surkhi, 1 sand.

84. **Sand.**—Sand used for mortar should be perfectly clean and free from clay or other impurities which would prevent the lime from adhering to it. The grains should be rough, sharp, and angular, and the sand should be the coarsest available. Sand containing salts is unsuitable for mortar as by attracting moisture it is apt to cause damp and efflorescence. The weight of a cubic foot of dry clean sand is about 100 lbs.

85. **Surkhi.**—Surkhi is generally made by pounding old bricks or the brickbats obtained from kilns. When these are not available, it is made from round balls of clay specially prepared and burnt for the purpose. If a large quantity is required it is usually ground fine under a roller in a circular mill worked by bullock or steam power. The presence of lime in the clay burnt has a great influence on the manufacture of surkhi. Clays containing 10 to 20 per cent. make the best surkhi if they are underburnt or "pila." Those containing little or no lime have to be thoroughly burnt or "pakka" to bring out their excellent qualities. Clays containing a large proportion of sand are not so suitable for making surkhi as those which, having more alumina in their composition, are greasy to the touch.

Surkhi is most useful for mortar in joints of walls and for hydraulic works, but its use for plaster or pointing exposed to weather is not to be recommended as, like the bricks from which it is usually made, it is apt to disintegrate after a time and crumble away under the destructive influences of air and humidity. Hydraulic lime and clean sharp sand make the best mortar for plaster and pointing.

The weight of a cubic foot of surkhi is about one maund or 80 lbs.

86. **Tests of mortars.**—Mortars are tested with a view to ascertain their resistance to crushing, their adhesiveness to bricks or stone, their

cohesion or tensile strength, the time they require to harden, and the amount of sand or surkhi which may be safely and economically used in their composition.

The crushing resistance is easily ascertained by loading a sample under test weights to the point of destruction. The safe crushing strain on brickwork or stone masonry laid in ordinary hydraulic lime mortar (1 to 1½) is usually assumed to be five tons per square foot; the ultimate or breaking strain ten to twelve tons. The actual crushing strain of brick work in Portland cement mortar, 1 cement to 2 sand, is 20 tons per square foot; the safe strain may be taken to be 8 to 10 tons.

The adhesiveness and tensile strength or cohesiveness of mortars are tested in the manner described above for limes and cement.

The time required to harden, and the best mixtures of lime with sand or surkhi or both, to give the desired results, can only be ascertained by actual experiment with samples on a small scale. Briquettes should be made of mixtures in which the ingredients are used in different proportions and these should be tested for strength and hardness after periods of a day, a week, a month, three months and six months. The mixture giving the best result should be adopted for the work. Some samples should be kept under water and others buried in damp sand. Rondelet estimated 15 to 20 lbs. per square inch as the adhesive strength of ordinary mortar in a joint of brickwork after six months and 7 lbs. per square inch as the *detrusive* force required to shear the joint acting parallel to it as in the abutment of an arch at springing level. The adhesive strength of Portland cement mortar (1 to 4) after 28 days is about 25 lbs. per square inch.

87. The *tensile strength* of ordinary lime mortar of average strength (1 to 1 or 1½) is 80 to 120 lbs. per square inch after three months. The tensile strength of Portland cement mortar 1 cement to three sand after a week is 150 to 200 lbs. per square inch.

88. **Bulk.**—The *bulk* of mortar produced in proportion to that of the ingredients differs according to the quantity and description of the sand or surkhi added to it but for the ordinary mixtures of 1 lime to 1½ or 2 of sand or surkhi it may be roughly assumed to be about two-thirds.

89. **Grout.**—Is a very thin liquid mortar which is sometimes used for filling up empty joints and crevices of brickwork or masonry left in consequence of bad workmanship. It is also necessary sometimes for filling up deep and narrow joints between large stones. It is deficient in strength and is only used in special cases where it is unavoidable.

90. **Precautions in the use of mortar.**—In using hydraulic limes and cements, the necessity of thoroughly soaking the bricks or stones in water before laying them in mortar should be carefully observed. If the moisture is suddenly drawn off any hydraulic mortar it will not harden. Dry bricks and most stones absorb a large quantity of water and if laid dry take it up from the mortar between them which crumbles into powder. Compact stones such as granite, marble, etc., being very dense absorb but little water and in laying these it is sufficient to water their surfaces just before use, but porous materials such as sandstone and bricks should be allowed to soak in water for some hours before use.

91. Mortar should be used as stiff as it can be spread. All the joints should be well filled and grout should never be used except where, from the position of the joint, it cannot be filled by mortar of proper consistency.

92. The work should be kept well wetted for a week or ten days after it has been laid, to prevent the rapid drying of the mortar, especially in hot weather.

Mortar exposed to the action of frost before it has set is seriously damaged. When frost is expected during construction, the foundations and walls up to at least three feet above ground should be laid in quick setting hydraulic mortar, as the action of the frost is most severe at and near ground level. All building should, if possible, be suspended during severe frosts.

93. **Concrete.**—Concrete is made by mixing lime or cement with sand or-surkhi and some hard material such as broken stone, burnt clay, broken brick, etc. These ingredients are thoroughly mixed in the dry state and water is then added to form a sort of conglomerate which is carefully laid in position where required and rammed hard to make it compact. The broken material is usually called the *aggregate* and the mortar in which it is embedded the *matrix*.

The proportions of lime or cement and sand or surkhi should be such as will give a mortar of the required strength and quality for the work for which the concrete is intended. The points to be attended to in this respect are the same as those explained above for "mortar." As a rule, the mortar for concrete should be better than that used for walling, as in concrete the mortar receives less assistance from the form and arrangement of the bodies it cements together than it does in masonry or brickwork.

94. The aggregate is generally any hard material that can be procured near at hand without great expense. Any hard substance may

be used in small pieces—broken stone, gravel, shingle, broken brick, burnt clay, slag, bits of earthware or breeze. If there is any choice, preference should be given to porous material such as pieces of brick, sandstone or limestone rather than to smooth substances such as flint and shingle, as the former offer rougher surfaces for the mortar to adhere to. Angular fragments should be preferred to those consisting of rounded pieces, e.g., broken stone rather than gravel or shingle. Aggregate of a very absorbent nature should be thoroughly soaked in water before it is mixed with the mortar otherwise it will suck all the moisture out of the matrix and greatly reduce its strength.

The aggregate is generally of an average size that will pass through a 1½″ or 2″ mesh but for very important work it may be much smaller down to ¾″. The size of the pieces influences the content of the void spaces between them and therefore the quantity of mortar that must be used. The voids in a hundred cubic feet of broken stone or brick 1½″ to 2″ in size may be taken roughly to be 35 to 40 cubic feet. The actual contents of the void spaces in any aggregate may be ascertained by filling a watertight box of known dimensions with the material and measuring the quantity of water poured in to fill up all the interstices. A mixture of pieces of different sizes, as is usually found in a stack of broken material, reduces the amount of voids and is desirable.

Where large masses of concrete are used, as in heavy foundations, it is the practice to pack in large lumps of stone, vitrified brick, etc., in the interior for the sake of economy. These lumps should be placed two or three inches apart at least and not touching one another, and they should be some distance clear of the face so that they are entirely surrounded by cementing matter.

95. The usual proportion of matrix to aggregate in India for ordinary concrete in foundations is 40 cubic feet of mixed dry mortar to 100 cubic feet of aggregate about 1½″ size. For walls, arches, bed blocks, sewers, etc., where very compact concrete is essential, the proportion of dry mortar is increased to 50 cubic feet per hundred cubic feet of aggregate broken to a size varying from ¾″ to 1¼″. A mixture of 100 cubic feet aggregate 1″ to 1½″ size and 40 cubic feet dry mortar laid and rammed yields about 110 cubic feet finished concrete.

96. The materials should be measured out in a dry state in the proportions decided upon by measuring boxes, and then thoroughly mixed together on a clean platform of concrete or brickwork. They should be turned over in the heap at least twice, or better still three times, to be most thoroughly incorporated. The dry mixture should then be sprinkled

from a watering can with a rose, no more water being used than is necessary to mix the whole very thoroughly. The mixture should again be twice turned over and then carried at once to the position where it is to be laid.

Concrete should never be tipped or slid into position from a height, as this causes the separation of the heavy and light particles in falling and results in a concrete which is not uniform throughout its mass. After mixing it should be rapidly wheeled to the place where it is to be laid and gently turned over into position, where it should be carefully and steadily rammed in layers not exceeding 12 inches in thickness. The layers should be horizontal to prevent the water running off and carrying away some of the mortar with it.

97. Concrete is chiefly used for the foundation of Engineering structures, and for filling in the spandrils of arches or the hearting and backs of thick walls. The material has so improved lately that it is now employed for many other purposes, among which may be mentioned the following:—The walls of houses in continuous mass, in blocks or in the form of slabs built into timber or iron quartering; retaining walls; reservoirs; arches; stairs; flooring of different kinds; paving slabs; window sills and lintels; steps; ornamental mouldings; roofs.

98. The safe crushing strength of ordinary lime concrete is usually assumed to be 5 tons per square foot; of ordinary Portland cement concrete 8 to 10 tons.

99. **Plaster.**—Good brickwork composed of bricks of very hard quality and thoroughly well burnt does not, as a rule, require plaster to preserve or beautify it, but there are many cases in which it is quite legitimate to use plaster.

If the stones or bricks of which a structure is built are not so hard and durable that they are capable of resisting permanently the disintegrating effects of weather, they should be protected by a covering coat of plaster, but in this case the materials of which the plaster is composed should be imperishable. Lime and sand are of this nature but underburnt clay is not, and it is advisable therefore to avoid as far as possible the use of *surkhi* in plaster for external work which is not derived from thoroughly well burnt hard bricks. A slightly hydraulic lime, with only a small quantity of clay in it, thoroughly slaked and mixed with sharp clean sand makes a suitable mortar for external plaster. If the use of white lime and *surkhi* is unavoidable, great care should be taken to see that the *surkhi* is from thoroughly well burnt clay. Cement and sand are suitable material

for external plaster if carefully mixed and laid on, but cement is too expensive for ordinary work; cement plaster is generally used in India as an internal lining of reservoirs and dams, to make them watertight, and sometimes to provide a non-absorbent surface in the floors of bath rooms, kitchens, etc.

100. Plaster is used for the interiors of rooms to give a smooth surface, and when there is a special object in providing a smooth surface to throw off rain water quickly as in the case of a brick vault or an arched roof.

It happens occasionally that plaster is required for the ornamental features of a building which it would be too expensive to construct in carved stone or specially moulded bricks, and sometimes it has to be used to harmonise with the appearance of other buildings in the neighbourhood.

101. Outside plaster differs very little in its nature from ordinary mortars used in building. As, however, less strength is required in plaster than in mortar, it is usual to mix a larger proportion of sand or surkhi with the lime. The presence of sand is positively beneficial up to a certain point, as it diminishes the shrinkage of the plaster in drying and prevents cracks. Fresh water and sand taken from fresh water should always be used in preparing mortar for plaster, as the presence of any salt causes constant damp on the walls.

102. When plaster is laid in two or three coats, the first coat should be scratched while moist with a succession of lines crossing each other like trellis work, to provide a rough surface to which the next coat may adhere. In India, plaster for external work is generally consolidated by being patted for some time with a small wooden trowel called a "thapi." For internal work it is sufficient to "float" the plaster, that is to lay it on fairly moist, and smoothen it by passing a straight edge in different directions over its surface.

103. **Stucco.**—is plaster worked to resemble marble. It is generally made of lime mixed with calcareous powder, gypsum and various other substances; it becomes very hard and is capable of receiving a fine polish. It is usually laid on in three coats; the first very coarse; the second finer and forming a smooth even surface, and the last coat composed of rich lime thoroughly slaked and passed through a fine sieve and mixed with pounded white marble or gypsum (calcium sulphate). The required colour is obtained by mixing with the lime certain metallic oxides such as oxide or carbonate of copper for blue, yellow oxide of lead for yellow,

litharge or calcined ochre for red. When the stucco is dry, it is polished. The surface is rubbed with a very fine grained stone, washing and clearing it at intervals with a sponge. It is then rubbed with a bag of linen containing moistened chalk, then with oil and chalk, and lastly with oil alone.

The "*chunam*" used in the Madras Presidency is a species of stucco. It is laid on in 3 coats. The first is a mixture of shell lime and sand with a solution of coarse sugar (gur). The second is made from sifted shell lime and the finest white sand without the addition of *gur* which would discolour the plaster. The third coating which receives the polish is prepared with the greatest care; the best and whitest shells being selected for the lime and mixed with about one fourth of their volume of the finest white sand. The ingredients of the second and third coats are ground in a small rolling mill to a smooth uniform paste resembling white cream. In about every bushel of this paste are mixed the whites of a dozen eggs, half a pound of clarified butter (ghee) and a quart of sour curded milk (dahee) to which is added about a quarter of a pound of powdered soapstone. The last coat is laid on very thin and rubbed with the smooth surface of a piece of soapstone for several hours to produce a fine polish. Water exudes from the plaster for several days after the work is finished which should be wiped off at frequent intervals. Masons in Upper India use other ingredients than those mentioned above for stucco plaster. As these vary in different parts of the country a specification of each of these cannot be attempted in this manual. They can be ascertained by inquiry from the masons in each district where the work is to be done.

104. **Whitewash.**—The interior walls of Indian houses, and some times the exterior, are generally whitewashed instead of being painted or papered. Whitewash is merely a thin solution of slaked lime with some ingredient as glue or rice water (kanje) to render it adhesive to the walls. When whitewashing an old wall, the former coat of whitewash should be scraped off, as the new coat will not adhere to the old one properly.

CHAPTER VI.

TIMBER.

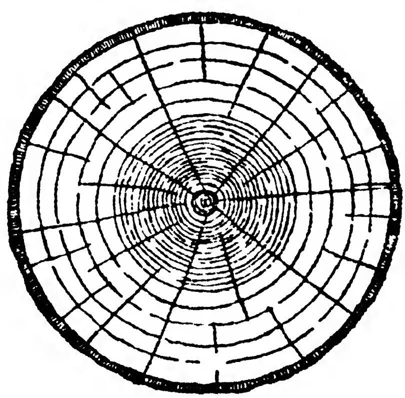
105. Different kinds of timber.—Wood suitable for building or engineering purposes is usually called *timber.* When it forms part of the living tree it is called *standing timber ;* when felled it is called *rough timber ;* after the log has been sawn into the various forms in which it is required such as beams, battens, posts, planks, etc., it is called *converted timber.*

All trees from which timber is derived are *exogenous*, that is they grow in girth by depositing annually a new layer of material between the previous year's growth and the bark. A cross section of such trees show a series of concentric rings. These are called "annual rings", as each ring represents one year's growth. Palms and tree-like reeds, such as bamboos and canes are *endogenous* ; so called, because, although the stem grows partly by the formation of layers of new wood on its outer surface, the fibres of the new wood so cross and penetrate those previously formed as to be mixed with them at one part of their course and *internal* to them at another. The stems of such trees though light and tough are too flexible and slender to furnish material suitable for important engineering works.

106. Growth and structure.—The innermost part or core of a timber tree is called the *pith.* This is enclosed by the *heart wood* which is the oldest and hardest part of the tree and is used for all durable wood-work. The outer and younger rings which are generally of a lighter colour are called *sapwood.* Outside the sapwood occurs a single thin ring of soft material known as the *cambium layer* which is covered by the *bark.* If this layer is exposed by the removal of the bark so as to prevent its functional action, the tree usually dies.

The rings nearest the core are almost invariably thinner and darker than those near the bark, the change being gradual across the section.

Fig. 6.



From the cambium layer thin horizontal veins of fibrous tissue extend radially towards the core, and other veins of the same nature extend outwards from the pith towards the bark. These hold the annual rings together and are called *medullary rays.*

The material forming the annual rings consists of innumerable closed cells arranged one over the other in the form of vertical tubes, crossed by horizontal diaphragms, and the conveyance of sap from the root to the leaves and back again is effected through these tubes. The transference of moisture can only be effected by *absorption* through the cell membranes forming the horizontal diaphragms, and solids cannot be absorbed at all except in solution.

In spring, the sap rises from the roots, chiefly through the sapwood, and forms leaves. When it reaches the leaves, it parts with much of its moisture by evaporation, and thickens. By an elaborate process which need not be discussed here, the leaves absorb carbon dioxide (CO_2) from the air and decompose it, freeing its oxygen and retaining the carbon which is added to the sap. This thick sap now descends in the cambium layer and is deposited on the inner side to form a new annual ring outside that deposited in the previous year. When the sap is decending the leaves become detached from the twigs and gradually fall off. This occurs in Autumn. When all the leaves are off, the sap stops flowing and vegetation ceases till next Spring. When the flow of sap ceases in winter, the cells of the sapwood are always left with an accumulation of reserve material, which is utilised to produce buds in the early part of the following Spring when the moisture begins to rise again.

Sapwood containing thick elaborated sap is liable to attack by worms or vegetable growth, in stagnant air and moisture, and it is therefore now considered best to fell timber in midsummer, when the rising sap consists of nothing more than water and mineral salts in solution which can be readily disposed of by *seasoning,* natural or artificial, as explained below. Felling in Spring or Autumn when the sap is most vigorous in its movement should be avoided.

The heart wood increases in hardness until a tree has acquired its full growth, but if a tree is allowed to stand too long decay sets in, and this always begins with the heart wood, which is then found to be weaker than the outer rings. It is, therefore, important that a tree should be felled for timber just as it reaches full maturity or very soon after if the best results are desired. For important work, heart wood alone is used. Sapwood, especially in the outer rings, is soft and liable to decay and therefore unfit for work which is intended to be durable.

107. **Seasoning.**—Timber produced from a newly felled tree is full of sap, and if this is not expelled by drying or seasoning the wood is liable to shrink, warp, rot and develop cracks or shakes, after it has been placed in position. It should, therefore, not be used in a green state. After it has been felled, the log, roughly squared, should be dried gradually by being stacked on stone or brick supports a little above the ground, with a free space between each log for circulation of air. The drying yard should be well drained and the logs should be sheltered as far as possible from high winds and the direct rays of the sun. This is called *natural seasoning* and is the best method of seasoning when time can be spared for it, as it renders wood tough and elastic. Wood, thus seasoned, is however only fit for carpenter's work after two years and for joiner's work after four years. Artificial methods have therefore been adopted to effect the seasoning more rapidly. These methods are briefly described below.

Water seasoning is the simplest artificial method. It consists in immersing the timber in water as soon as it is cut. After a fortnight's soaking it is taken out and dried in an airy place. The logs should be sunk entirely under water, partial immersion being most injurious. This plan, though rendering timber less liable to warp and crack, undoubtedly weakens it and should therefore be avoided where great strength is required. It is very beneficial when the wood is very green and full of sap, and is required quickly for work of an ordinary nature, as it removes most, if not all of the fermentible matter, and renders the wood less liable to be worm eaten and to decay by rot.

108. **Boiling.**—Is another method of seasoning timber. It tends to impair the strength and elasticity of timber but reduces its liability to shrinkage. It is useful when joiner's work has to be executed in wood which takes a long time to season naturally. Timber should not remain long in boiling water or steam; four hours is generally sufficient. The drying after it is removed from the water should be slow and gradual.

109. **Smoking** and *charring* timber is sometimes resorted to. It can only be done on a small scale, and only if the wood is fairly dry. If green timber is charred and buried in the ground or placed in an unventilated situation, decay is sure to result, as the sap which is then confined in the tree ferments and produces dry rot.

110. The best method of artificial seasoning known is the *dessicating process*, which consists in exposing the timber in a chamber or oven to a current of hot air. This is driven into the chamber at such a rate

that the air passed through it per minute is equal to one-third the cubical capacity of the chamber. The best temperature of the hot air varies in each case with the kind of timber, its size and shape. Hard woods in large pieces require a temperature of 90° to 100°. Fir woods 120° to 200°.

111. **Decay and preservation.**—Timber lasts best when kept dry and well ventilated. Wet timber is softened and weakened, but does not necessarily decay, if kept constantly immersed, and some varieties which are comparatively useless in the air are very durable under water; the Cotton tree is a remarkable instance of this. Timber soon decays if it is placed in positions where it is alternately wet and dry unless great precautions are taken for its preservation as described below. Slaked lime is very destructive to timber which should never therefore be placed in immediate contact with it in buildings.

Timber has to be preserved from moisture, from internal decay or dry rot, and from the attacks of insects, the most destructive of which in India is the white ant.

Oil paint on seasoned wood preserves it from moisture and prolongs its life indefinitely if the paint renewed occasionally, but it is very important to see that the wood is thoroughly seasoned before the paint is applied, as otherwise the paint would confine the sap by filling up the outer pores and cause decay.

Many processes have been adopted for protecting timber from dry rot and insects by impregnating it with various chemical substances, such as chloride of zinc and sulphate of copper, but the one which has proved to be most successful, practically and financially, is that known as *Creosoting*. This is effected by first exhausting the air and moisture from the wood in an airtight vacuum chamber, and then pumping in the Creosote under a pressure of 120 lbs. per square inch and at a temperature of about 120°F. The timber should be thoroughly well seasoned and artificially dried for 24 hours before it is treated. Commercial creosote is a dark brown thick oily liquid, obtained from coal tar, of which it constitutes from 20 to 30 per cent. It is produced by distillation of the tar at temperatures ranging from 350° to 700°F.

112. **Classification.**—Timber is classified broadly under the two heads, *fir wood* and *hard wood.*

Fir trees usually have long straight trunks and short branches. They are coniferous and contain turpentine. Fir wood has a well defined fibrous texture, and as it is obtained in long straight logs it is very useful where

long pieces are required to bear either a direct pull or a transverse load. The lateral adhesion of the fibres is however small, and for this reason it is not well fitted to withstand stresses which do not act longitudinally along the fibres. It is easily split or torn asunder across the grain.

Hard wood contains no turpentine. Its fibres have more adhesion than those of fir wood and it is closer grained. It is therefore more suitable for resisting compression and irregular cross strains.

113. **Qualities of good timber.**—There are certain qualities which are characteristic of strong and durable timber; these are given briefly below:—

(a) Narrow annual rings indicating slow growth.

(b) Darkness of colour.

(c) Heavy weight.

(d) Firm adhesion of fibres and compact medullary rays.

(e) Smooth and hard appearance at a freshly cut surface; a dull chalky appearance is a sure sign of bad timber.

114. **Varieties of Indian timber trees.**—In Appendix B is given a comprehensive list of the trees of India prepared by Colonel A. M. Lang, R. E., a past Principal of the Roorkee College. The following is a brief description of the trees most commonly converted into timber in the Upper Provinces:—

(1) **Deodar.**—Coniferous. Found in the Himalayas at altitudes above 7,000′; a tall straight trunk with short horizontal branches—long needle leaves. Grain close and well marked; a light coloured wood. Looks well when planed and varnished. Light and easily worked, but strong and durable. A very valuable timber and used largely for building and railway sleepers.

(2) **Chir.**—Coniferous. Found in the Himalayas at altitudes from 4,500′ to 7,000′. Somewhat similar in appearance and texture to the Deodar, but coarser grained and inferior in every way. Useful where strength and durability are not important considerations.

(3) **Sal.**—An upright straight tree found in the lower valleys at the foot of the Himalayas. Large dark leaves. The wood is close grained and has a dark brown colour. It is hard and very heavy. It is easily worked but it does not take a fine polished surface; very strong and durable, and most valuable for all but ornamental purposes.

(4) **Sain.**—Very similar to sal but inferior in quality. Wood is of a lighter colour. It also grows in the lower parts of the Himalayas; requires a practised eye to distinguish it from sal.

(5) **Kikar.**—Grows all over Upper India. The tree has many branches, a dark coloured bark and light feathery foliage. The wood is of a dark red colour, hard and strong. It is seldom obtainable in any large size, so it is not much used for building purposes. Well curbs are generally made of it, and it is sometimes used for lintels, door frames, etc., in small unimportant buildings.

(6) **Teak.**—Grows in Burma. A very large tree with numerous branches and large light coloured leaves. The wood is close grained and of a rich yellowish brown colour, hard, and fairly heavy. It is easily worked and takes a smooth polished surface. Is of great strength and durability, and suitable for any work from shipbuilding to furniture making. One of the most valuable timber trees in the world.

(7) **Tun.**—Found all over the plains of India. A spreading tree of moderate size, short trunk and large branches, abundant foliage, leaves long and pointed. Not available in large scantlings, so it can only be used for furniture and such like work, for which it is eminently suitable, as the wood is rich red brown in colour, close grained, and can be worked to a fine polished surface.

(8) **Sissu or Shishum.**—Found all over India. Similar in appearance to tun, but its leaves are round. The wood is dark brown in colour but somewhat coarse grained. It does not work quite so smooth as *tun* but is moderately good in this respect. When available in large scantlings it is used for beams and planks. It is chiefly used for carriage building. The wood is fairly hard and durable.

(9) **Mango.**—Grows all over India. The wood is white and coarse grained and of no great strength or durability. Only used for rough work in unimportant buildings.

(10) **Simal.**—Found all over India and Burma. A lofty tree with straight trunk and large straight branches. Wood is poor and white but it lasts well under water, so it is commonly used in subaqueous foundations and for well curbs.

(11) **Bamboo.**—The smaller varieties grow in the low hills at the foot of the Himalayas; the larger in Bengal and Burma. It is not strictly speaking a timber tree. Bamboos are commonly used for various minor purposes in connection with buildings, chiefly for frames of thatched roofs, for scree gratings and light partitions.

If fuller details are required by those specially interested in Indian trees the following works may be advantageously referred to.

"Timber trees of India" by Balfour.

"Forests and Gardens of South India" by Cleghorn.

"Indian and Burma Timber" by Skinner.

CHAPTER VII.

METALS.

115. The metals chiefly used by the Engineer and builder are *iron*, *copper*, *zinc*, *tin*, and *lead*, and some of their alloys such as *brass*, *phosphor bronze*, and *gunmetal*. The elementary metals above mentioned are not found as a rule in a pure metallic state but in combination with oxygen forming oxides, with sulphur as sulphides, and with carbonic acid as carbonates. Such natural compounds of the metals are called *ores*. These ores are usually found in the older geological formation—mica sehists, clay slates and sometimes even in granite. Iron is the largest exception to this, as it is also obtained in large quantities in the carboniferous formation and sometimes from still more recent strata.

The metallic ores occur in these natural beds or strata in detached masses called *lodes* or *veins*. These appear to have been forced into the beds when they were in a fluid state under powerful pressure. To reach these veins of ores, deep *mines* are usually sunk with numerous underground *passages*, *levels*, *adits*, etc. The result of the mining operation is to bring to the surface the ore more or less mixed with earthy matter. To separate and remove this earthy matter the ore is *dressed*.

116. **Dressing.**—The pure ore is first picked out by hand as far as possible. The remainder is broken up in stamping or crushing mills, and washed in a stream which carries away the lighter impurities leaving the ore.

117. **Calcination and roasting.**—The ore is then roasted in heaps, or in a kiln, to drive off the moisture and carbonic acid or sulphur. This operation also renders the mass more porous and therefore better fitted for the successful carrying out of the next process which is *smelting*.

118. **Smelting.**—The ore is mixed with a substance called a "*flux*," selected for its tendency to combine with the particular impurities of the ore. The mixture is thrown at intervals into a continuous kiln or furnace with a certain proportion of fuel, usually coke, and subjected to intense heat, which reduces the ore to a fluid condition. The heavy

metal sinks down to the bottom of the furnace, where it is tapped, while the impurities combine with the flux and run off through a higher opening in the form of a light and fusible *slag.*

119. **Iron and steel.**—Iron ores are generally carbonates or oxides of the metal, the latter being generally the best. As they occur in beds or strata they can usually be obtained sufficiently pure by the miner, and therefore seldom need the preliminary operations of dressing and roasting.

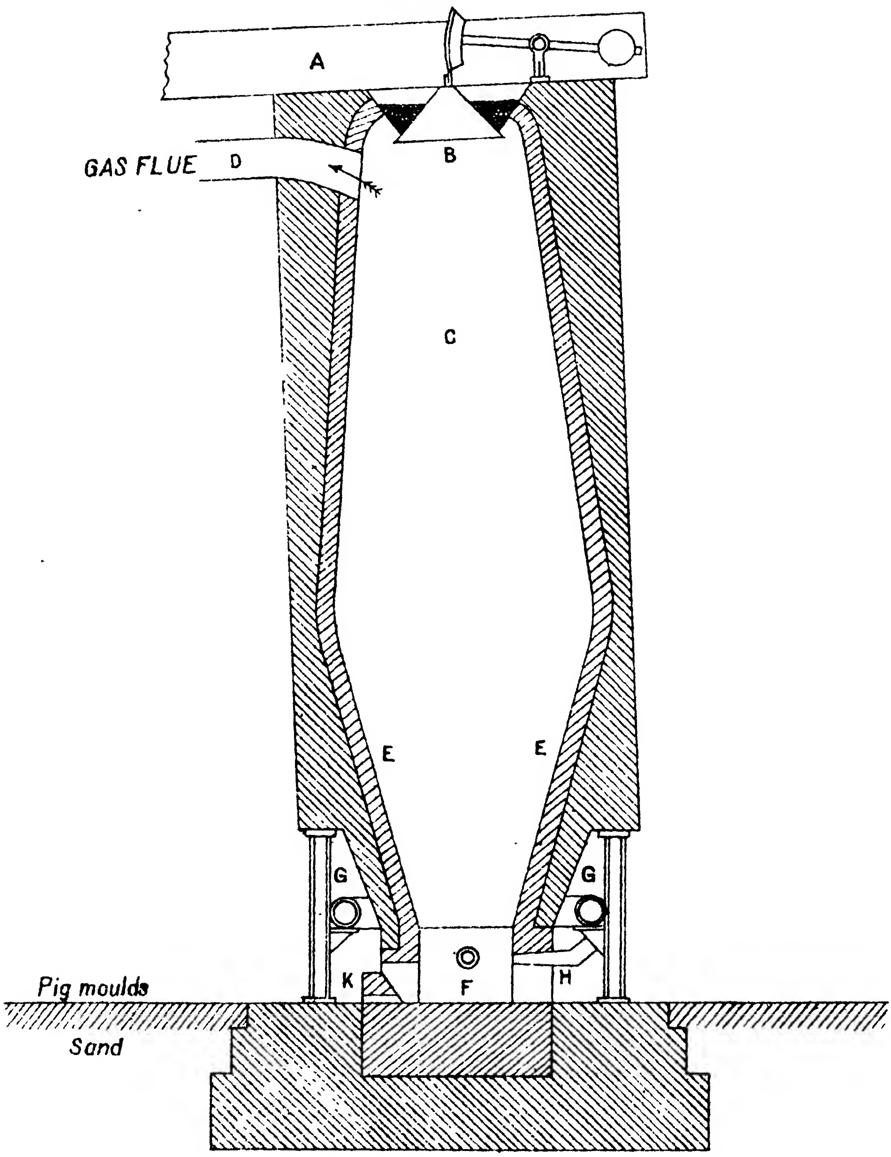
120. **English ores.**—The iron ore now used in England is chiefly imported from Bilbao in Spain, the richer veins of English ore being mostly worked out or nearly so, that which is left giving so small an output of metal as to be unprofitable to work. The most important English ore now worked is that from the Cleveland Hills, near Middleborough. The best seam, 10 feet thick, yields 30 per cent. of iron, but this too is now largely worked out and much of it that is now being smelted yields only 26 per cent.

121. **Indian ores.**—Valuable iron ores have recently been discovered in India – in Bengal and the Central Provinces. These are now being worked profitably by the Bengal Iron and Steel Company and by the Tata Steel Institute. A Note on the ores worked by the former Company and the processes by which iron and steel are manufactured from them, by Mr. J. Angus, Consulting Engineer of the Company in London, will be found in Appendix C. Besides the mines above referred to, iron is found in many other parts of India—in the Salem and Beypur districts of the Madras Presidency, in the Vindhya Hills near Jabalpur, in Jhansi and Gwalior, in Assam and Burma and various other parts. Copper is found in Kumaon and Rajputana. Tin in Burma and Malacca. Appendix D contains useful information extracted from the Memoirs of the Geological Survey of India regarding Indian metals.

122. **Smelting.**—The extraction of iron from the ore (previously dressed and roasted if the ore requires this preliminary treatment) is effected in a tall pear-shaped smelting furnace lined with firebrick, see Fig. 7. The intense heat to which the ore is subjected in this furnace frees the metal from its combinations as far as possible, and separates the impurities from the iron in the form of a fusible slag. To effect this a flux is added which combines with the impurities in the ore. If the impurity, or "*gangue*" as it is called, is chiefly clay, the flux used is broken limestone. If the gangue is mostly sand or quartz, an argillaceous

iron ore and limestone are added. If the gangue is limestone itself, clay or clayey ores are added.

Fig. 7.



The smelting, or blast furnace as it is usually called, is first filled to a certain height with fuel. When this is burning brightly, a mixture of ore and flux is introduced from the top through the hopper and cone arrangement shown in the figure; then layers of ore, flux, and fuel, are

added at intervals. A furnace once lighted is not allowed to go out until repairs are necessary, being continually replenished with ore, fuel, and flux, at the top.

The charging apparatus above the furnace consists of a fixed circular shaped cast iron hopper into which the materials are tipped, and a moving central △ steel cone suspended from a chain with a counter-weight. The cone is drawn up as shown in the figure when the hopper is charged. To discharge the contents the cone is allowed to drop below the bottom of the hopper.

Immediately below the charging apparatus is a flue which carries off the gaseous products of combustion, consisting chiefly of inflammable carbon monoxide (C O), which is utilised either to heat the air blast or to generate steam in boilers working the air compressing plant.

123. A strong blast of air is forced into the furnace. Formerly this blast was supplied at the ordinary temperature of the air. This is still done sometimes, the process being called *cold blast* and the iron produced *cold blast iron*, but of late years the *hot blast process* has been generally adopted. In this, the air is raised to a temperature of 1500° Fahr. before it is forced into the furnace. By this a great saving of fuel is effected and higher temperatures, up to 2000° Fahr., are obtained in the furnace. Moreover, calcining or roasting is often dispensed with, and it becomes possible to use coal as fuel instead of coke. The blast is forced into the furnace through small nozzles called "tuyeres" surrounded with coils of W. I. pipe through which water circulates to keep them cool.

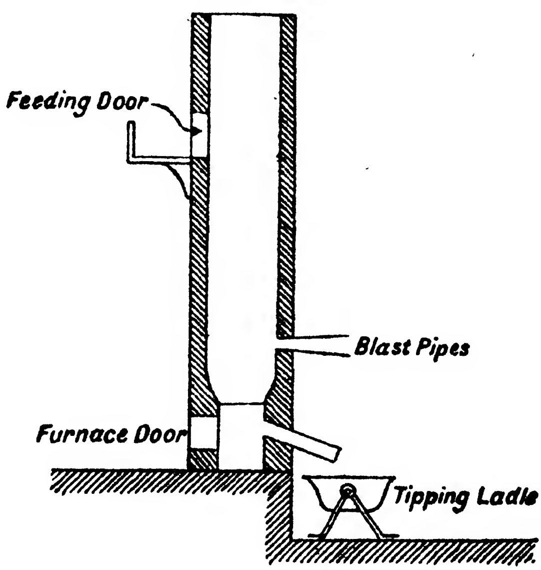
124. The intense heat in the furnace reduces and melts the ore, the iron which it contains sinking, from its heavier weight, to the hearth at the bottom, while a lighter scum of impurities, known as slag, floats above it, the burning ore being above that again. When the molten matter has reached a sufficient depth, just below the tuyere openings, a hole is opened at such a level as to allow the floating slag to escape. This is run out in a trough and either used for paving-bricks or deposited in waste heaps. The furnace is then tapped by making a small hole in a fireclay stopping at hearth level. Molten metal runs out and is received in long straight gutters made in sand which have numerous side branches where it cools and solidifies. This arrangement is called the *sow* and her *pigs* and hence the name the iron now receives of *pig iron*.

125. **Pig iron.**—This is usually sold, in the form of rough bars, to the founder or the iron manufacturer, by whom it is subjected to various refining processes and converted into cast iron, wrought iron or steel as described below. It always contains a certain proportion of foreign

substances among which are carbon, silicon, sulpur, phosphorus and manganese. Of these, that which plays the most important part is carbon. The great differences that exist between cast iron, wrought iron and steel depend largely upon the amount of carbon they respectively contain. The other substances may generally be regarded as impurities, though each of them, when present, plays an important part in determining the characteristics of the finished product, and in some cases their presence is actually beneficial. In this connection it is important that the student should from the outset bear in mind, that roughly speaking, cast iron contains from 5 to 2 per cent. of carbon, steel from 2 to 0·25 per cent., wrought iron 0·25 to 0·1 per cent. Between these limits there are several gradations merging gradually one into the other to which no definite classification can be assigned.

126. **Cast iron** is obtained by remelting the pig iron of commerce and running it into moulds of the shape required. In some cases for rough castings, the metal is run in direct from the blast furnace, but for superior work it is generally the practice to remelt the pigs in a furnace called a "*cupola.*" The cupola is very similar to the blast furnace and is worked in the same way but it is smaller in size. See Fig. 8. A little limestone is added as a flux, which combines with some of the impurities left in the pigs, and removes them in the form of slag.

Fig. 8.



There are several varieties of cast iron but it is usually classified under the three main heads. Grey cast iron, white cast iron and mottled cast iron.

127. Siliceous ores melted with a large proportion of fuel at a high temperature produce a metal containing silicon which assists the crystal lisation of the contained carbon. This is *grey cast iron*, which has a bluish grey fracture showing distinct crystals, and a large dark and bright grain. It is readily fusible and is very suitable for delicate castings but is not of great strength. It is commonly used for conversion into steel.

128. Non-siliceous ores melted with a smaller proportion of fuel and at a relatively low temperature, produces a metal containing little silicon, and the carbon in it is uncrystallised. This is *white cast iron*. It has a white silvery fracture, is hard and brittle and of little use for castings except of the roughest kind. It is chiefly used for conversion into wrought iron.

129. **Mottled cast iron.**—Lies between grey aud white and is really a combination of both. It is a good material all round for castings.

130. When treated with nitric acid a recent fracture of grey iron shows a black stain while that of white iron shows a brown stain.

White and mottled cast iron are less liable to rust than the grey kind. They are less soluble in acids, hard and brittle.

131. **Moulding.**—The preparation of moulds and the operation of moulding are difficult and complicated processes which will be best learnt by the student in the College Workshop. They will not be dealt with in this Manual.

The shape given to castings requires careful consideration. All changes of form should be gradual, and all angles, both external and internal, should be rounded off. Sharp corners and angles are a source of weakness and frequently cause cracks in castings on cooling. There should be no great or abrupt difference in the bulk of the adjacent parts of the same casting or the smaller portions will cool and contract more quickly than the larger parts, placing the casting under severe internal stress before it is called upon to bear any external load at all.

132. **Examination of castings.**—In examining castings, the Engineer should see to the following points:—

The exterior surface should be smooth and clear and the edges should be sharp and perfect. An uneven or wavy surface in a casting indicates

unequal shrinkage caused by want of uniformity in the texture of the iron.

The surface of a recent fracture should show a fine grained texture of an uniform bluish grey colour and high metallic lustre.

The metal of a casting should be free from scoriae, core nails and air bubbles. Bubbles are a common and dangerous source of weakness. They should be searched for by tapping the casting all over with a hammer. Bubbles or flaws filled in with sand cause a dulness in the sound which leads to their detection.

If the castings are to be subjected to severe compressive or transverse strains, as in girders and columns, the metal should be tested for strength as specified in paragraph 152.

133. **Wrought iron.**—This variety of iron is now seldom used for structural work, having been almost entirely replaced by mild steel, but it is still used to a great extent for conversion into hard steel, for small forgings and for ornamental work where a tough material is required which can be easily bent or welded.

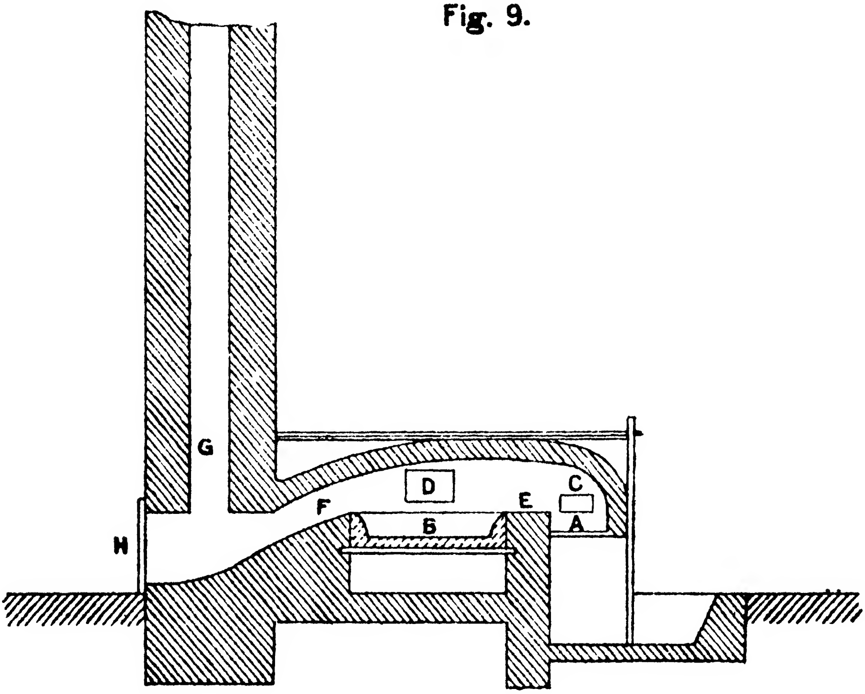
It may, by a certain process, be obtained direct from the ore, but it is generally manufactured from the harder descriptions of pig iron by a series of processes which remove the carbon and the phosphorous, silica, and other impurities, which tend to make the iron brittle and otherwise defective. To expel these foreign substances the best qualities of wrought iron are first *refined* and then *puddled* but the refining process is omitted for the inferior qualities.

Pig iron of the white or forge variety is generally used for the manufacture of wrought iron; this can be converted at once by the puddling process. If grey iron is used, the silicon it contains makes it difficult to puddle and it becomes necessary to remove it by the preliminary process of refining.

134. **Refining.**—Consists in exposing pig iron in a melted state to a strong current of air on an open hearth. It is well stirred while the air is passing over it, so that all parts of it are brought into contact with the air and oxidised. The oxygen in the air combines with the carbon in the iron and removes a part of it. It also converts the silicon into silica which combines with some of the iron and runs off in the form of a fusible slag.

135. **Puddling.**—Consists in re-melting the pig iron, refined or in its original state, in a reverberating furnace, a section of which is shown in Figure 9.

Fig. 9.



The burning fuel in this furnace is separated by a partition from the hearth on which the metal is melted, the flame only being conducted over its surface, while the puddler by means of a rake or *rabble* keeps it thoroughly agitated. When molten, substances containing oxide of iron such as haematite ore, forge scales, etc., and sometimes limestone and common salt are introduced. These remove the rest of the carbon and also combine with any silicon there may be in the iron which is thus oxidised and runs off as a slag. As the carbon is removed the iron becomes less fusible, and collects in lumps in a pasty condition, which are brought together by the puddler with rakes through a side door and formed into *puddle balls*. These lumps or balls are at once placed under a steam or tilt hammer the blows of which force out the cinder and weld the particles of iron together forming it into what is known as a *bloom*. This hammering process is called *shingling*. Directly after this, the red hot iron is passed between grooved rollers which convert it into puddled bars 10 or 12 feet long, three inches wide and an inch thick.

136. **Rolling.**—The puddled bars formed as above explained are wrought iron but of a very inferior quality. They hardly have any of the characteristics of the higher qualities and have to be improved by further processes of piling, reheating and rolling.

They are cut into short lengths which are "piled" or tied together with wire, reheated in a reverberatory furnace and again rolled. A repetition of the process produces what is known in the trade as "best" bar. A second repetition produces "best best" and a third repetition "best best best" bars.

The effect of rolling on wrought iron is most important as it alters its structure and strength to a very great extent. All wrought iron after exposure to high temperatures sufficient to cause softening or pastiness, consists of an aggregation of crystals of a cubical shape. By rolling, these crystals are elongated into fibres which form the texture of all good wrought iron.

The tensile strength is also greatly improved by rolling.

137. **Defects.**—Defective wrought iron or mild steel is either "cold short" or "red short." Cold short iron or steel is brittle when cold and cracks if bent double, though it can be worked at a high temperature. This defect is found as a rule in an iron produced from a poor ore containing an excess of *phosphorus.* Red short, or hot short iron or steel, cracks when bent at a red heat, but is sufficiently ductile and malleable when cold. This defect is generally due to *sulphur* taken up from the fuel. Red short metal is useless for welding but is tougher than other metal when cold.

The effect of *silicon* in iron or steel is to make it hard and brittle, i.e., cold short.

Manganese up to a certain limit (1 per cent.) is beneficial as it counteracts the red shortness produced by sulphur in wrought iron and steel.

138. **Qualities of good wrought iron.**—A recent fracture should have a clear bluish-grey colour with a high silky lustre and a fibrous appearance; when the texture is either distinctly laminated or crystalline, the metal is defective. It is tough, malleable, ductile, and moderately elastic. At a white heat it becomes soft enough to take any shape under the hammer and admits readily of *welding*, i.e., of two pieces being thoroughly joined together by heating and hammering.

139. **Different forms.**—Wrought iron is manufactured for engineering purposes in the following shapes:—

Bar iron in long bars of rectangular section distinguished by the dimensions of the section as 3″ × 1½″ bar, 2″ square bar, etc.

Rod iron in long cylindrical rods, the different sizes of which are similarly specified, as ½ inch rod, 1 inch rod, etc.

Iron wire similar to rod iron but in much smaller sections—wire differs from rod iron chiefly in the method in which it is made. It is *drawn* when in a red hot pasty condition through circular holes in a strong metal plate, not *rolled* as rod iron.

L, T,] *and* H *irons* called respectively *angle, tee,* channel and H irons. These are made in long lengths of the sections indicated by their names.

Plate, sheet and hoop iron.—In long flat strips. The wider varieties are called sheet iron if less than ¼″ thick and plate iron if thicker. Narrow thin strips are known as hoop iron.

Sheet and hoop iron are rolled between smooth cylinders.

All the other varieties, except iron wire, are given their shapes by indentations in the peripheries of the rollers between which they are passed.

A very useful form of sheet iron which should be specially noticed is that of *corrugated* iron, which is produced by passing the sheets between rollers with grooved peripheries. The strength and stiffness of the sheet by being corrugated is so much increased, that in this form it can be usefully employed for a great variety of purposes for which it would otherwise, owing to its thinness and pliability, be utterly unsuitable.

140. All the above mentioned articles are manufactured by the makers in different standard sizes, and in designing structures it is desirable that one or other of these sizes should be adopted in the design if possible. Special shapes and sizes, not of the standard types, are difficult to obtain and are much more expensive. The market sizes will be found fully detailed in the catalogues of Messrs Dorman Long & Co., and other leading manufacturers.

141. **Steel.**—This form of iron is broadly classified under two main heads, (1) high carbon steel containing from ·5 to 1·5 per cent. of carbon, from which tools and other articles requiring very hard surfaces are made, and (2) low carbon or mild steel containing ·15 to ·5 per cent. carbon, which is generally used for structural work as it has many of the qualities of good wrought iron and has greater strength.

Steel is usually manufactured either from wrought iron by what is known as the "*cementation*" process, or from pig iron by first completely decarbonising it and then adding the proper percentage of carbon. The former process produces the harder varieties of steel from which tools, etc., are made, and is not of such interest to the Structural Engineer as the latter by which mild steel is manufactured which is the material chiefly employed for structural work, for rails and for the working parts of machinery such as crank shafts, connecting rods, etc. The first process will therefore be only lightly touched upon and the latter described in greater detail.

142. **Cementation process of manufacture.**—The manufacture of steel from wrought iron, known as the "*cementation*" process, consists in placing bars of the purest wrought iron in a furnace, between layers of charcoal powder, and subjecting them to a high temperature for a period varying from 5 to 14 days according to the quality of steel required. This process is called cementation. The wrought iron bars absorb carbon from the charcoal dust, and become covered with a mass of blisters, from which the steel thus manufactured is called *blister steel.* As the outer surface of the bars in this process absorb more carbon that the interior, the layers produced are of varying quality. To make the mass more uniform and improve the quality of the steel, the bars are broken up, reheated in a reverberatory furnace, hammered and rolled as in the manufacture of wrought iron. The steel thus becomes more fibrous and is known as *shear steel.* If the process of heating, and rolling is repeated, the product is known as *double shear steel.* Even this class of steel is not very homogeneous and is not suitable for the best class of work. To overcome this defect, fragments of blister steel are melted in fire clay crucibles without the addition of any carbon, and when the metal is liquid it is run into ingot moulds and then hammered and rolled. This is known as *crucible cast steel.* It is harder and more homogeneous in texture, and a recent fracture shows a distinctly crystalline appearance.

143. **Manufacture of mild steel.**—*Mild steel* is now manufactured almost exclusively from pig iron by the *Bessemer* and *Siemens-Martin open hearth* processes which are described below. The percentage of carbon in mild steel varies according to the class of work for which it is required. For railway and tram rails it is usually from 0·4 to 0·5 per cent.; for crank shafts, connecting rods, etc., from 0·35 to 0·5; for boiler plate and for bridge and roof work 0·15 to 0·3.

144. **Bessemer process.**—The *Bessemer* process is worked as follows:—Molten pig iron is run from a cupola furnace into a large

receiver called a *converter*, which is made of strong boiler plate lined inside with some refractory material and capable of revolving on a horizontal axis. At the lower end of the converter are a number of nozzles or tuyeres through which a strong blast of air is forced producing a very high temperature. See Figs. 10 and 11.

Fig. 10.
FRONT ELEVATION.

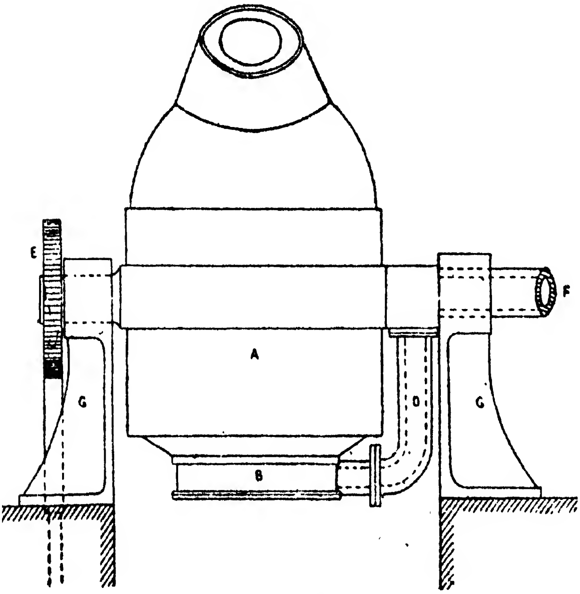
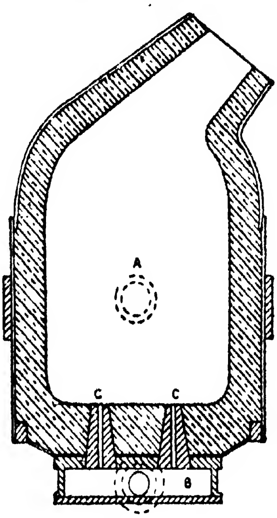


Fig. 11.
VERTICAL SECTION.



The converter is first heated by a charge of burning coke which is raked out after a time and the molten iron is then poured in. The blast is then introduced and the converter is swung into a vertical position. The blast is continued for about 18 or 20 minutes during which time important chemical changes take place which are indicated by the colour and character of the flame and sparks emitted. The carbon and impurities are then completely removed and when this has occurred a stream of white hot nitrogen from the air of the blast alone escapes. The very high temperature inside the converter is produced by the rapid oxidation of the carbon and silicon present in the molten iron by the air of the blast, and the addition of fuel is unnecessary. When the combustion is complete, the converter is swung over into a horizontal position and the blast is turned off. A carefully measured quantity of ferro-manganese, which is determined by the actual percentage of carbon required in the steel, is then thrown in and the blast turned on again for

a short time to ensure its being thoroughly mixed with the charge. The metal is now converted into *Bessemer steel* which is poured out into ladles and run into ingot moulds.

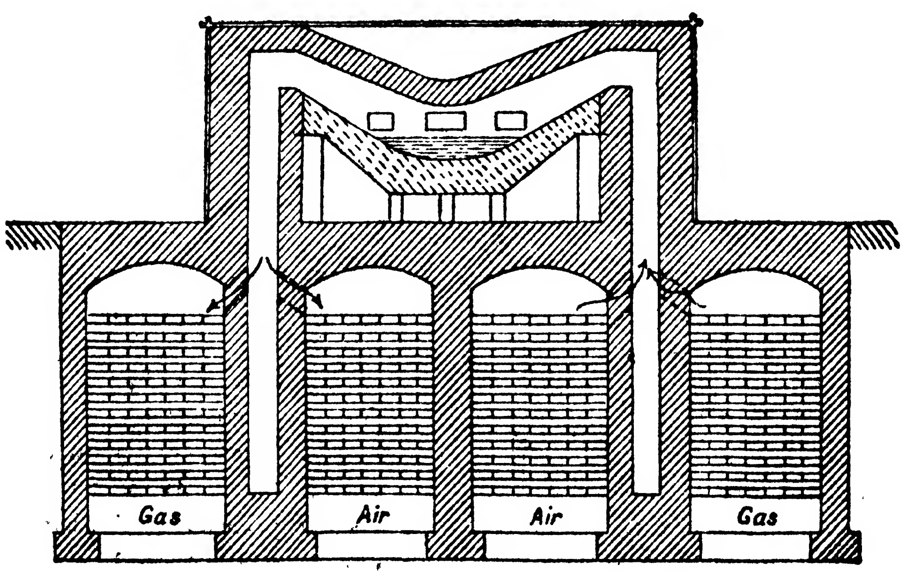
The ferro-manganese added to the molten metal in the converter consists of pure iron combined with 4 to 10 per cent. of manganese and 5 per cent. of carbon. It is used to provide the necessary amount of carbon the steel is intended to contain.

If the pig iron is from a pure haematite ore and free from phosphorus, the converter is lined inside with ganister, a highly silicious material which is refractory at high temperatures and *acid* in character. If the pig iron contains phosphorus a *basic* lining of dolomite is necessary. Phosphorus can only be eliminated freely in the presence of a base capable of forming a stable phosphate with the oxidised phosphorus. Non-phosphoric ores are comparatively rare and costly, so a basic lining is more commonly used

145. **Siemen Martin's open hearth process** is somewhat similar to puddling. The furnace is of the reverberatory type, but instead of having a fireplace it has gas and air inlets at either end and a system of four regenerators. These are large chambers filled with fireclay or silicious acid bricks arranged in layers in open order to form a grating underneath the furnace. See Fig. 12.

Fig. 12.

LONGITUDINAL SECTION.



The source of heat is a mixture of air and coal gas. The furnaces are charged either with pig iron and ore, or a mixture of pig and scrap iron, to which iron oxide in the form of haematite is afterwards added. When the furnace has been heated and set to work, the gas and air pass through two of the regenerating chambers on their way to the furnace. The products of combustion escaping at a very high temperature pass through the other two chambers before going to the chimney and heat up the brick gratings in these chambers. After an hour or so the direction of flow is reversed. The entering gases now pass through the two highly heated regenerators where their temperatures are raised to a high degree. When they reach the furnace their heat is sufficient to keep the charge on the hearth in a liquid condition. By utilising a large proportion of waste heat this system leads to great economy in fuel.

The oxide of iron added to the charge removes the silicon by forming a silicate with it, which passes off as a slag. When all the carbon has been removed, leaving practically pure iron, a measured quantity of ferro-manganese is added, the carbon from which enters the iron and converts it into steel which is run off and poured into ingot moulds.

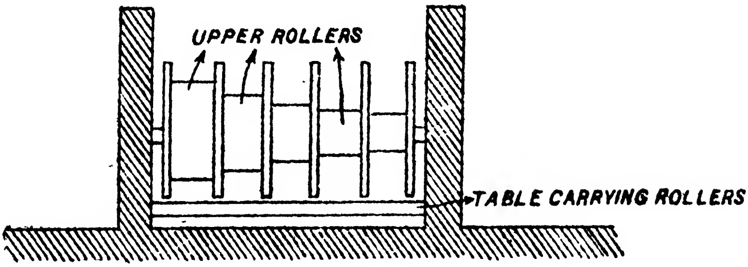
The open hearth process is more suitable than the Bessemer when a large quantity of mild steel is required of definite quality and chemical composition, as samples of the metal can be taken out from time to time and tested, and pig iron or ore added as may be found necessary while the charge is kept in a molten condition.

The lining of the furnace should be basic or acid according to the presence or absence of phosphorus in the pig as explained in the case of the Bessemer process.

146. **Rolling.**—The steel ingots moulded by both the Bessemer and open hearth processes are usually about 6 feet long and 18" to 24" square in section. By whichever process they have been produced, they are next reheated in furnaces and passed lengthwise between steel rollers, a simple set of which is shown in Fig. 13. The ingot is placed on the table of small lower rollers and guided by them between this table and the smaller set of the upper rollers. When it has passed through, it is longer and somewhat smaller in section. The motion of the rollers is then reversed in direction and the ingot passed back under the next larger roller and so on till it has passed under the largest roller, when it becomes a long bar of much smaller section. It is then cut into suitable lengths and passed between other rollers, both

of the same diameter, and grooved to give a bar of the actual section required such as rod, angle, tee or plate.

Fig. 13.



147. **Welding, case hardening and tempering.**—The process of joining two or more pieces of wrought iron or mild steel while in a semi-plastic condition at a white heat by hammering them when in contact with each other is termed "welding." The essential conditions for a good weld are (1) that the pieces be raised to a sufficiently high temperature and (2) that the surfaces at the joint be perfectly clean and free from oxide. The heating may be done either in an open fire for small pieces, or, for large important work, by passing a heavy current of electricity through the pieces while in contact. In the latter case the process is termed "electric welding."

"Case hardening" consists in making the outer surface of wrought iron or mild steel articles, which have to stand considerable wear, absorb a certain amount of carbon, thus converting it into hard steel, while the central parts remain softer and tough as in the link work of locomotives and the bearings of bicycles. The pieces to be case hardened are first machined and polished, then packed in air-tight boxes with substances rich in carbon, such as animal charcoal, leather, hoof-scraps, etc., and then gradually heated and kept at a high temperature for a considerable time. The articles are finally cooled in water and repolished.

"Tempering" is a process of great importance in the manufacture of cutting tools and springs. Its object is to give the articles the exact degree of hardness that is required. It is generally carried out in two steps, first "hardening" and then letting down to the required "temper." The article to be tempered is first heated to a dull red heat and then suddenly cooled in water. This makes it very hard and brittle. It is then tempered to the required degree of hardness by slowly reheating it to a moderate temperature and then gradually cooling it.

148. **Characteristics of steel**—It has a close grained bright crystalline fracture. The harder varieties can be cast. The softer varieties can be rolled, forged, welded and wire drawn. It can be tempered and is highly elastic. It can be permanently magnetised while wrought iron can only be temporarily magnetised, and cast iron cannot be magnetised at all.

149. **Different forms of manufacture**—High carbon steel is generally used as stated above for making such articles as machine tools, files, chisels, dies, etc. Low carbon or mild steel is manufactured in much the same forms as wrought iron, see paragraph 139.

150. **Preservation of iron and steel.**—Exposed to dry air, iron does not rust, but in damp air it corrodes rapidly, the rust forming with the iron a galvanic couple by which the corrosive action is increased. The principle involved in this fact has been utilised to protect iron from rust by at once forming a galvanic couple in which the iron shall be the electro negative element and so protected from corrosion. With this object in view, iron (especially sheet) is often covered with a thin coating of zinc. When so covered it is called galvanised iron. In this case the iron is protected at the expense of the zinc which is gradually decomposed. Carbon, copper, and lead, being electro negative to iron should never be placed in contact with it in structures, as they would set up galvanic action which would be injurious to the iron.

Coal tar, laid on hot, is one of the best surface protections of iron, but its black colour renders it objectionable where appearance has to be studied.

The protection of large Engineering structures is usually effected by the use of a metallic paint consisting chiefly of red oxide of iron, red lead, zinc oxide and boiled linseed oil mixed with a little turpentine which acts as a solvent. This gives a red colour. If any other colour is required, a suitable colouring pigment should be used to produce the desired effect.

Sea water as a rule has a much greater corrosive action on iron than fresh water. Dilute acids and certain salts in the soil also act readily on iron and produce rapid corrosion.

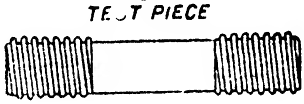
151. **Tests of strength and soundness.**—Next to calculating the various stresses to which the members of a structure or parts of a machine will be subjected, it is very essential especially on large works of importance, that the Engineer should ascertain by careful tests the strength and suitability of the iron or steel to be used. In practice, such materials are subjected to test compressive or shearing stresses, the

ultimate value of which for each metal is generally found by subjecting a specimen or specimens of the metal to be used to the particular stress it will have to bear in some form of testing machine. There are several of these machines in the College Workshops, and the students will no doubt be familiar with their use so they will not be described in this Manual. Nor will the usual data regarding ultimate resistances, safe working strains, moduli of rupture and elasticity, etc.. be given in this Manual as these will be found in the College Text Book of Applied Mechanics, and in the several standard specifications of steel and iron-work which have been issued recently by competent authorities, e.g., the India Office and the British Engineering Standards Committee. It will be sufficient to explain briefly here that the tests applied are roughly as follows :—

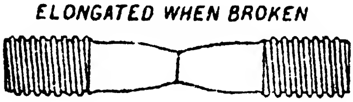
152. **Cast iron.**—In the case of castings in which strength is an important feature, as in water pipes under heavy pressures or columns carrying exceptional loads, test bars are run from the same metal as that used in the casting and tested by loading them as beams. These bars are 3′ 6″ long by 2″ deep and 1″ wide. They are set on bearings 3 feet apart with the two inch depth vertical and a test load is hung from the centre of the span. The breaking load so applied should not be less than 28 cwt. for iron of ordinary quality, or 30 cwt. for iron of special quality required for beams or machines subject to sudden shocks or extraordinary stresses. The minimum deflection under the same loads should be $\frac{1}{4}$ inch in one case and $\frac{5}{16}$ inch in the other.

153. **Wrought iron.**—The quality of this metal is ascertained by breaking in a machine test pieces of the metal 8 inches long and 0·5 square inch sectional area, screwed at each end to fit into the machine. See Fig. 14. These are broken by a longitudinal tensile strain to show the ultimate tensile contraction strength, the percentage of contraction in the section at the point of fracture, and the elongation in a given length of the material. For a medium quality of iron the tensile strength is for plates 18 tons per square inch and for bars 20 tons, the contraction being 10 per cent. for plates (along the grain) to 15 per cent. for bars and the elongation 8 per cent. for plates to 10 per cent. for bars. For an iron of special quality, the tensile strength is 21 tons per square

Fig. 14.
TEST PIECE



ELONGATED WHEN BROKEN



inch for plates and 23 tons for bars; the contraction 12 per cent. for plates to 22 per cent. for bars; the elongation 10 per cent. for plates to 18 per cent. for bars.

154. **Mild steel.**—The shape and dimensions of steel test pieces are the same as those of wrought iron. Tests for contraction of area are not usually applied to steel, the elongation being considered a sufficient indication of ductility. The ultimate tensile strength should be 27 to 31 tons per square inch and the elongation 20 to 25 per cent.

155. In applying the above tests to wrought iron and mild steel, the elastic limit or "*yield point*" should also be noted, as this is even a more reliable measure of their tenacity than the breaking strain or elongation. When these ductile materials are subjected to a gradually increasing load in a testing machine they stretch to a certain point and recover again to their original length when the load is removed. This is their elastic limit or yield point. When the load is increased beyond this point they stretch more rapidly without recovery till they ultimately give way.

156. In addition to the above tests, a cold bending test is also applied to wrought iron and mild steel in the form of plates and sheets. Wrought iron is tested along the fibres but steel may be tested with or across the grain. Sheets of No. 22 Birmingham Wire Gauge should bend double round twice their own thickness without any sign of fracture; No. 16 to No. 21 B.W.G. sheets round an angle of 130°: plates $\frac{1}{8}$ inch in thickness round an angle of 110°; plates $\frac{3}{16}$ inch thick round an angle of 90°. A convenient size for the test pieces is 8 inches by 6 inches.

157. **Copper, zinc, tin and lead.**—These metals are very little used by Engineers in structural work, so they will only be briefly described in this Manual.

158. **Copper.**—The ore of this metal is very widely distributed. It is sometimes found in a pure metallic condition, but it more often contains as impurities either iron, sulphur, antimony or arsenic. These impurities are extracted by the processes of roasting, smelting, and refining, in much the same way as that described in the case of iron. The high price of the metal enables the smelter to work ores which do not contain over two or three per cent. of metal.

159. It has a peculiar red colour. When tarnished it becomes green with a coating of subcarbonate of copper (*verdigris*) which acts as a preservative. It is peculiarly malleable and can be rolled into thin sheets or drawn into wire. In tenacity it is only slightly inferior to wrought iron, its tensile strength being 16 tons per square inch.

160. It is chiefly used in the Engineering works for conversion into electric wires or cables and lightning conductors, as its conductivity is very high, for locomotive fireboxes and pipes, for covering important roofs (especially domes), for dowels in heavy stone masonry and to form useful alloys with other metals.

161. **Zinc.**—This is obtained from either its sulphide (zinc-blende) or its carbonate (calamine). These are roasted and, after mixture with coke or charcoal, subjected to a process of distillation by which the zinc, on account of its volatility, is easily separated. It is brittle at ordinary temperatures, but at about 250°F. it becomes malleable and can be rolled into sheets which are sometimes used for roofing, gutters and flashing. It is largely used for galvanising iron sheets and pipes. It soon oxidises on the surface, but the film of oxide remains adherent and protects the metal beneath from further oxidation. Where the air contains acid particles, as near the sea, it is soon destroyed.

It is used in combination with copper to make *brass*, a most useful alloy.

162. **Tin.**—This metal is not much used by the Engineer in its pure state, but is useful in forming alloys and solder. It is occasionally used as a protective covering for iron plates. It is obtained from an ore called "tin stone," a binoxide. The ore is crushed, roasted to expel sulphur and arsenic, mixed with flux and smelted in a reverberatory furnace whence the liquid metal is run into moulds. The moulded ingots are then refined.

Tin is very soft, fusible and malleable, and is not readily oxidised. Its tensile strength and ductility are very low.

163. **Lead.**—The ore of this metal is always its sulphide (galena). It is obtained from the ore in much the same way as copper and tin, i.e., by the processes of roasting, smelting and refining.

It is extremely soft and plastic, very malleable, fusible, heavy and deficient in tenacity and elasticity.

It is much used by the builder for flat roofs and flashing and for linings of cisterns. It is often used by the Engineer as a bedding for the ends of girders, for joints of water pipes, and for other minor purposes.

In using lead for tanks and pipes it should be noted that soft or pure water, especially if charged with air or organic matter, acts upon lead in such a way that some of it is taken up in solution and the water is poisoned. This makes lead a dangerous material to use if such water is to be used for drinking purposes. It has been found, however, that water charged with certain salts which exist in many natural waters

prevent this action altogether. Such salts are the carbonates and sulphates, especially those of lime, which are very common in most spring waters, and usually in sufficiently large amount to prove a perfect protection. Recently boiled or distilled water should never be put in leaden vessels.

When a fresh surface of lead is exposed to air or water, it becomes rapidly coated with a thin gray film of oxide which protects the metal against further oxidation, unless some acid is present which is capable of dissolving the oxide.

164. **Alloys**.—Alloys are intimate mixtures of two or more metals made by melting them together. They are not mere mechanical mixtures, as they often exhibit properties different to those possessed by the metals in the mixture.

In preparing alloys, the metals of which they are composed are melted in pots or crucibles, generally of plumbago, the less fusible metal being melted first and the others added subsequently in order one by one, the most fusible coming last. The crucibles are plunged into the heart of the furnace and the contents, when thoroughly mixed, are run into ingots, these being remelted in the same way when castings are to be moulded from them. If there is a considerable difference in the specific gravities of the metals they must be continually stirred while fluid, or the heavier will sink to the bottom and the alloy will not be homogeneous.

Copper-tin and *copper-zinc* alloys are widely used for all classes of Engineering work, but especially for the bearing parts of machinery and for scientific instruments. Copper-tin alloys are called *bronzes* and copper-zinc alloys are known as *brasses*.

165 *Gun metal* is a bronze commonly used which is not liable to corrosion. The proportions of copper and tin vary from 80 copper 20 tin to 90 copper 10 tin, according to the kind of work for which it is required. The addition of a small quantity of zinc makes the metal more malleable.

It is tough, strong and hard and used chiefly for pumps, gland liners, valves and bearing parts of machinery subject to much attrition.

166. **Phosphor bronze** is an alloy of copper and tin with the addition of a small percentage of phosphorus, about 0·5 as a rule. It is a valuable metal, its strength being nearly equal to that of wrought iron, while it can be cast, forged or drawn into wire. The usual proportion of copper and tin is 85 copper to 15 tin. It has the advantage over gun metal that it can be remelted without injury. It wears longer than gun metal in bearings and is more useful in positions where it is subject to shocks.

167. **Brass** is one of the most important alloys in use. It consists usually of copper and zinc in the proportion of 2 of the former to 1 of the latter, but the proportion varies according to the class of work for which the brass is required. In melting the metals for a mixture the crucible has to be covered with charcoal powder and a close lid to prevent the zinc passing away in vapour.

Brass is tough as a rule, but is rendered brittle by continued vibration. It is more malleable than copper when cold, but cannot be forged at a red heat, because the zinc melts at a low temperature. Its fusibility increases in proportion to the quantity of zinc it contains. The addition of a little phosphorus makes it very liquid to run easily into castings.

It is a very tractable metal and takes a fine polish. It is easily burnished and kept bright.

It is commonly used for locks, door handles, hinges, screws, bushes and sockets, inscribed plates and light bearings.

168. **Solder** is the name given to several different alloys used for making joints between pieces of metal. Its effect is not merely mechanical as it combines with the metals to be united and forms a fresh alloy. The composition of the solder used for the different metals varies greatly, and the proportions in which each solder is mixed varies also according to circumstances. It is essential that the solder to be used should be more fusible than the metals it is to join together, and the more nearly the solder is like the metal in hardness and malleability the stronger will be the joint.

Hard Solders are those which fuse only at a red heat, and can therefore be only used for metals which will stand that temperature such as iron, copper, brass and gun metal. They are generally made of copper and zinc in proportions which differ according to circumstances. For brass work, the proportion is usually 1 to 1 and for copper and iron the proportion is 3 copper to 2 zinc.

Soft Solders melt at low temperatures and may be used for nearly all the metals. They are usually mixtures of tin and lead in varying proportions. Plumber's solder for joining gutters, cisterns and pipes is composed of 1 tin to 2 lead, while fine solder for superior brazing consists of 2 tin to 1 lead. Tin makes the solder more fusible, but it is much more expensive than lead so only so much is used as makes it fit for the purpose for which it is intended.

In soldering it is absolutely necessary that the surfaces to be joined be carefully cleaned and free from metallic oxides. To ensure the latter condition it is necessary to apply some protective solution just at the time of soldering which is known as a "flux." For this purpose borax is generally used with brass; sal ammoniac with iron and copper; chloride of zinc with zinc and tin; rosin with lead.

CHAPTER VIII.

MISCELLANEOUS MATERIALS.

169. **Paints.**—These are certain preparations used to provide a covering coat on the surfaces of wood, iron and other material to protect them from the destructive action of air and moisture or to improve their appearance.

170. The paints used by the Engineer consist essentially of a *base* which is usually an oxide of a metal, and some oily substance known as the *vehicle* with which the base is mixed to admit of its being spread evenly over the surface by means of a brush. In some cases a *solvent* is also necessary to make the paint work more freely and a *Drier* is often added to cause the vehicle to dry more quickly. If the final colour desired differs from that of the base, the actual tint required is obtained by adding a *colouring pigment.*

171 The materials commonly used are as follow:—

Bases—White lead, red lead, oxide of iron.

Vehicles—Linseed oil.

Solvent—Turpentine.

Driers—Litharge and red lead.

Colouring pigments—Red and yellow ochre, Prussian blue, verdigris (for green colour), Lampblack or finely ground Babool charcoal (for black colour).

172. **Bases of paints**—Of the bases above-mentioned, the one most commonly used is *White Lead* This is a carbonate of the metal. It is sometimes supplied as a powder but more often mixed in the form of a stiff paste with from 7 to 9 per cent. of linseed oil. Besides being used for oil paints it is frequently employed as a cement for jointing water pipes. It is insoluble in water but dissolves readily in nitric acid and also, if heated, in hydrochloric acid Unfortunately, white lead is highly poisonous both to those employed in its manufacture and to painters who use it much. It also has the defect of darkening considerably in impure air or in the presence of sulphur, so it cannot be used with very delicate colours such as ultramarine. In spite of these disadvantages it is more used for oil paints than any other base.

Red lead is a higher oxide of lead. It is sold as a bright red powder. It retains this colour permanently unless it comes into contact with any preparation containing lead, or acids mixed with lead, which deprive it of

colour. Impure air makes it black. It is used more as a *drier* than as a base, being mixed with white lead paints to make them dry rapidly. It is sometimes, however, mixed with linseed oil and used as a base for painting iron work and for making watertight joints. A little white lead is usually mixed with it when it is used for this purpose. It is also used frequently for the first coat on woodwork.

Oxide of iron is sometimes used as a base for ironwork paint, as it is supposed that lead or zinc paint sets up a galvanic action which tends to destroy the iron it is intended to protect. Oxide of iron paints are not effective in sea water.

173. **Linseed oil** is made by compressing flax seed. In its raw state it is pale in colour and almost transparent. It is used for mixing with bases and pigments for internal work not exposed to weather, and for delicate tints its use is imperative. Boiled oil dries much more quickly than the raw, becomes thicker, and is more weather proof. Mixed with a small quantity of litharge and red lead it is called *drying oil*, as its drying properties are much improved by this mixture.

174. **Turpentine** is obtained by distillation of the crude turpentine which exudes from pines. The distilled liquid is the commercial *spirit of turpentine*, generally known as *turps*, which is commonly used as a solvent for paints. The residuum of the distillation is the substance called resin (ral). Good turps has a pleasant pungent odour, is colourless and inflammable. It oxidises on exposure to the air and is converted into a resinous substance. Turpentine is not generally used for external or finishing coats of paint, as it does not stand exposures as well as oil, but it is often so used for white paint to avoid discolouration. If used at all in external work it should only be added in a small quantity, just sufficient to make the paint run readily with the brush.

175. **Litharge** is an oxide of lead produced in extracting lead from its ore or from the film formed on the surface of the metal when in a state of fusion. It is the drier most commonly used for lead paints.

176. **Colouring pigments.**—*Red and yellow ochres* are coloured earths. *Prussian blue* is a compound of iron and cyanogen. *Verdigris* is a carbonate of copper produced by the action of vegetable acids on copper. *Lampblack* is soot collected from the burning of resinous and oily matters.

The proportions in which the ingredients are used to form a paint vary according to the conditions under which it is to be used and the colour required. It is now the usual practice to buy paints ready made by firms of repute and to use them carefully as directed.

177. **Varnish** is a solution of resin in rapidly drying solvents such as oil, turpentine or alcohol. The solvent dries or evaporates and leaves a hard transparent film of resin on the varnished surface. It is used to brighten painted surfaces and protect them from wear and the action of the atmosphere. It is often applied to plain unpainted wood surfaces in the furniture and fittings of houses, to intensify and brighten the ornamental appearance of the grain. It is also sometimes applied to painted and papered walls.

178. **Distemper.**—The colouring of plastered walls is commonly done in India with a solution composed of some colouring material mixed with water and size * instead of oil. This is known as *distemper.* For *whitewash* pure lime is used instead of the colouring material. The colours chiefly used for this purpose are *red and yellow ochre*, the flowers of the "*dhak*" tree which give a pink or light orange colour, *or pigment* (hurtal) a yellow coloured mineral composed of sulphur and arsenic, blue vitriol (nilatutya) a sulphate of copper. Combinations of these colours are employed to produce drab, stone colour, etc., and the depth of colour is reduced at pleasure by the addition of white lime. If carefully done with plenty of size this kind of work looks very well. If it is decorated with borders in darker colour, cheaply laid on with stencil plates in ornamental patterns, it is possible to produce good artistic effects.

179. **Wall papers.**—These may be divided into three classes (1) common or pulp paper, (2) satin paper, (3) flock paper.

In *pulp paper* the ground is the natural colour of the paper as first made and the pattern is printed on it.

Satin papers have a polished lustre like that of satin. They are made by painting the paper over with the colours desired and then polishing it with some powdered French chalk. These papers are very liable to be affected by damp, even from the paste used in hanging them, so they should be hung with great care on dry walls with a protective paper lining. They keep clean for a long time as their smooth surface prevents adhesion of dust and dirt.

Flock papers are not often used. The designs on them are formed by the adhesion of cork dust or "flock" sheared off from the surface of woollen cloths. The pattern is first printed on the paper in size, next in varnish, and the flock or cork dust then sprinkled on, which by adhering to the varnish forms the pattern. These papers are distinctly handsome, but they catch dust readily and cannot be kept clean.

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* Size is made by boiling glue in water, a pound of glue makes a gallon of size. Indian masons often use 'kanji' a strong decoction of rice, as size for whitewash.

The printing of patterns on paper is usually done by hand by means of wood blocks, a separate block being used for each colour.

180. **Glass.**—The glass used in buildings is a mixture of pure sand, soda, and chalk, with a certain proportion of broken glass. These are melted together at a very high temperature and brought into the shapes required by different processes which need not be described here, as an engineer is never likely to be called upon to make glass for himself.

There are three different varieties of glass in the market: (1) crown glass, (2) sheet glass, (3) plate glass.

Crown glass is now seldom used and need not be described in detail.

Sheet glass, used generally for doors and windows, varies much in composition, but may be considered roughly to consist of 100 parts pure sand, 35 parts chalk or limestone, 40 parts sulphate of soda, and 50 parts broken glass. It is sold in varying lengths and thicknesses, the latter ranging from 1/15″ (weight 15 ounces per sq. ft.) to 1/5″ (weight 42 ounces per sq. ft.).

Plate glass is thicker than sheet, its thickness ranging from 3/16″ to 1″. It is made of the purest materials, the following being a typical mixture:—white sand 100 parts, soda carbonate 33 parts, slaked lime 14 parts, manganese peroxide 0·15 parts and broken glass 100 parts. It is suitable for any position where a very strong translucent material is required. Light is admitted without glare or excessive heat, and in winter it keeps out the cold more effectively than thin sheet glass. It is commonly used for skylights, glass houses or conservatories, and roofs of all kinds; also for windows of factories, railway stations, etc. This description of glass is sometimes made with plain grooves or with patterns raised or indented on the surface when it is known as *rolled or fluted glass.*

In addition to the above, there are two other minor varieties of glass which are often used and need mention. *Obscured or frosted* has one side covered with a film which is produced either by grinding the surface or by melting powdered glass on it; this is used wherever light is required without transparency. *Stained or coloured glass* is made in every variety of tint by adding metallic oxides and other substances to the materials before fusion, or by covering plain sheet glass on the side only with a thin layer of coloured glass. In the latter case, designs are formed in the glass by erosion of the coloured layer where it is not required by means of fluoric acid.

181. **Asphalt.**—Strictly speaking *asphalt* is bitumen or mineral pitch, but the name is also commonly applied to a combination of bitumen and calcareous matter which is found in many places in France,

Germany and Switzerland. The latter is usually known as *rock asphalt.* Artificial preparations composed of bitumen, rock asphalt, and sand in varying proportions, are made by certain firms and sold under the name of asphalt, but such preparations are more generally known in the trade as *mastics.*

Bitumen is found in lakes in Trinidad and Texas, on the shores of the Dead Sea in Judea, and in the island of Cuba. Its origin is obscure, but it is commonly believed to have been produced by the oxidation of hydrocarbons of petroleum. Its composition is roughly 85 parts carbon, 12 parts hydrogen, and 3 parts oxygen.

Rock asphalt, a natural limestone impregnated with bitumen, is found chiefly in the Val de Travers (Switzerland), in Seyssel (France), at Limner (Hanover, Germany). It is known in the market by the names of the places where it is found. It is composed roughly of 80 to 90 per cent. limestone and 10 to 20 per cent. bitumen.

For buildings and roads, asphalt is generally used in the form of *mastic,* which is a mixture in varying proportions of natural asphalt, sand and bitumen, or coal tar.

The method of preparing and laying asphalt or mastic is fully described in the Manual on Building Construction.

Asphalt or mastic is waterproof, easily applied in a melted state, and to some extent elastic. These quantities make it a very useful material for engineering purposes. It is often employed for lining tanks, for damp courses of walls, and as a waterproof layer over arches or flat roofs; also for smooth non-absorbent floors of wash-houses, latrines and kitchens. It provides a good wearing surface for footways and carriage drives, but it is slippery in wet weather and is apt to soften under high sun temperatures. Good mastic should withstand a temperature of 140° to 160° Fahr. without softening appreciably, and should not become so fluid as to run much below 260° F.

182. **Coal tar.**—This is made by heating coal in closed vessels and is usually obtained as a bye-product in manufacturing coal gas. When itself distilled, it produces at different stages of distillation, *naphtha, creosote* and *pitch.* If its black colour is not an objection, it is commonly used as a preservative paint for wood work, and ironwork exposed to weather. It is also used for asphalt work and as an ingredient of varnishes, etc.

APPENDIX A.

BRITISH STANDARD SPECIFICATION FOR PORTLAND CEMENT.

[*Revised March*, 1915.]

1. Composition and Manufacture of Cement.

The cement shall be manufactured by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperate and grinding the resulting clinker, so as to produce a cement capable of complying with this Specification.

No addition of any material shall be made after burning other than calcium sulphate, or water, or both, and then only if desired by the Vendor and not prohibited in writing by the Purchaser.

2. Samples for testing and by whom to be taken.

A sample or samples for testing may be taken by the purchaser or his representative, or by any person appointed to superintend the works for the purpose of which the cement is required or his representative, or by any expert analyst employed or instructed by such Purchaser or person, or the representative of such Purchaser or person.

3. Samples for testing and how to be taken.

Each sample for testing shall consist of approximately equal portions selected from twelve different positions in the heap or heaps when the cement is loose, or where there is a less number than twelve different bags, barrels, or other packages, then from each bag, barrel, or other package. Every care shall be taken in the selection, so that a fair average sample may be taken.

4. Sampling Large Quantities.

When more than 250 tons of cement is to be sampled at one time separate samples shall be taken, as provided in Clause 3, from each 250 tons or part thereof.

5. Facilities for Sampling and Identifying.

The Vendor shall afford every facility, and provide all labour and materials, for taking and packing the samples for testing the cement and for subsequently identifying the cement sampled.

6. Cost of Tests, Analyses and Samples.

The test and chemical analyses herinafter mentioned other than those referred to in clause 16, shall (unless otherwise provided in the contract between the Vendor and the Purchaser) be made at the expense of the Purchaser, but no charge shall be made by the Vendor for the cement used for samples or for carriage thereon.

7. Tests.

The sample or samples shall be tested in the manner hereinafter mentioned for:—

(a) Fineness.

(b) Specific gravity.

(c) Chemical composition.

(d) Tensile strength (neat cement).

(e) „ „ (cement and sand)

(f) Setting time.

(g) Soundness.

And before any sample is submitted to tests *(d)*, *(e)* *(f)* and *(g)*, it shall be spread out for a depth of 3 inches for 24 hours in a temperature of from 58 to 64 degrees Fahrenheit.*

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* The temperatures stated are applicable to temperate climates. In other climates special arrangement between Vendor and Purchaser must be made unless the temperature herein stated can be artificially obtained in the laboratory or other place where the tests are made.

8. Tests for Fineness.

The cement shall comply with the following conditions of fineness :— 100 grammes (or say 4 ozs.) of cement shall be continuously sifted for a period of 15 minutes on each of the undermentioned sieves, and in the order of succession given below, with the following results :—

(1) The residue on a sieve $180 \times 32\,400$ meshes per square inch shall not exceed 14 per cent.

(2) The residue on a sieve $76 \times 76 = 5{,}776$ meshes per square inch shall not exceed 1 per cent.

The sieves shall be prepared from wire-cloth and the diameter of the wire for the 32,400 mesh shall be ·0018 inch and for the 5,776 mesh, ·0044 inch The wire-cloth shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

9. Test for specific gravity.

The specific gravity of the cement when presented by the Manufacturer for testing shall be not less than 3·10.

10. Test for chemical composition.

The cement shall comply with the following conditions as to its chemical composition. The proportion of lime to silica and alumina when calculated (in chemical equivalents) by the formula $\frac{CaO}{SiO_2 + Al_2O_3}$ shall be not greater than 2·85 nor less than 2 0* The percentage of insoluble residue shall not exceed 1·5 per cent., that of magnesia shall not exceed 3 per cent., and the total sulphur content calculated as sulphuric anhydride (SO_3) shall not exceed 2·75-per cent. The total loss on ignition shall not exceed 3 per cent.

11. Test for tensile strength (neat cement.)

The breaking strength of neat cement shall be ascertained from briquettes of the shape shown in Fig. 1. Plate 1. The briquettes shall be prepared in the following manner.

The cement shall be mixed with such a proportion of water that the mixture shall be plastic when filled into the moulds used for forming the briquettes.

The cement, gauged as above, shall be filled into moulds of the form required to produce briquettes of the shape shown in Fig. 1, Plate 1, each mould resting upon a non-porous plate. In filling the moulds the operator's hands and the blade of the ordinary gauging trowel shall alone be used. The trowel shall weigh about 7½ ozs. No ramming or hammering in any form will be permitted nor shall any other instrument or apparatus other than the trowel before described be employed for this operation. The

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* Example.—In the case of a cement containing 63·28 per cent. of lime, 21·6 per cent of silica and 8·16 per cent. of alumina the proportion of lime to silica and alumina would be as follows :—

Molecular weight of lime = 56
,, Silica = 60
,, Alumina = 102

$$\text{Lime } (CaO) = \frac{63\cdot28}{56} = 1\cdot13$$

$$\text{Silica } (SiO_2) = \frac{21\cdot6}{60} = 0\ 36$$

$$\text{Alumina } (Al_2O_3) = \frac{8\cdot16}{102} = 0\cdot08$$

$$\text{Then } \frac{CaO}{SiO_2 + Al_2O_3} = \frac{1\ 13}{0\cdot36 + 0\cdot08} = 2\cdot57$$

moulds after being filled may be shaken to the extent necessary for expelling the air.

Clean appliances shall be used for gauging, and the temperature of the water, and that of the test room at the time the above operations are being performed, shall be from 58 to 64 degrees Fahrenheit.

The briquettes shall be kept in a damp atmosphere for 24 hours after gauging, when they shall be removed from the moulds and immediately submerged in clean fresh water and left there until taken out for breaking. After they have been so taken out and until they are broken the briquettes shall not be allowed to become dry. The water in which they are submerged shall be renewed every seven days and shall be maintained at a temperature of between 58 and 64 degrees Fahrenheit.

The briquettes shall be tested for breaking strength at 7 and 28 days respectively after gauging, six briquettes for each period. The breaking strength shall be the average tensile breaking strength of the six briquettes for each period. The briquettes to be tested shall be held in strong metal jaws of the shape shown in Figs. 2 and 3, Plate 1, and the load shall be steadily and uniformly applied, starting from zero, and increased at the rate of 100 lbs. per square inch of section in 12 seconds.

The breaking strength of the briquettes at 7 days after gauging shall be not less than 450 lbs. per square inch of section.

The breaking strength of the briquettes at 28 days after gauging shall show an increase on the breaking strength at 7 days, and shall be not less than the number of pounds per square inch of section arrived at from the following formula:—

$$\text{Breaking strength at 7 days} + \frac{40{,}000 \text{ lbs.}}{\text{Breaking strength at 7 days.}}$$

12. Test for Tensile Strength (Cement and Sand).

The breaking strength of cement and sand shall be ascertained from briquettes also of the shape shown in Fig. 1, Plate 1. The briquettes shall be prepared in the following manner.

A mixture of cement and sand in the proportion of one part by weight of cement to three parts by weight of the standard sand shall be gauged with sufficient water to wet the whole mass throughout without any excess of water being present.

The mixture gauged as above shall be evenly distributed in moulds of the form required to produce briquettes of the shape shown in Fig. 1, Plate 9, each mould resting upon a non-porous plate. After filling a mould a small heap of the mixture shall be placed upon that in the mould and patted down with the Standard Spatula shown on Plate 2 until the mixture is level with the top of the mould. This last operation shall be repeated a second time and the mixture patted down until water appears on the surface ; the flat only of the Standard Spatula is to be used and no other instrument or apparatus is to be employed for this operation. The mould after being filled may be shaken to the extent necessary for expelling the air. No ramming or hammering in any form will be permitted during the preparation of the briquettes, which shall then be finished off in the moulds by smoothing the surface with the blade of a trowel.

Clean appliances shall be employed for gauging, and the temperature of the water and that of the test room at the time the above operations are performed shall be from 58 to 64 degrees Fahrenheit.

The briquettes shall be kept in a damp atmosphere for 24 hours after gauging, when they shall be removed from the moulds and immediately submerged in clean fresh water, and left there until taken out for breaking. After they have been so take out

and until they are broken the briquettes shall not be allowed to become dry. The water in which they are submerged shall be renewed every seven days, and maintained at a temperature of between 58 and 64 degrees Fahrenheit.

The briquettes shall be tested for breaking strength at 7 and 28 days respectively after gauging, six briquettes for each period. The breaking strength shall be the average tensile breaking strength of the six briquettes for each period. The briquettes to be tested shall be held in strong metal jaws of the shape shown in Figs. 2 and 3, Plate 1, and the load steadily and uniformly applied, starting from zero and increased at the rate of 100 lbs. per square inch of section in 12 seconds.

The breaking strength of the briquettes at 7 days after gauging shall be not less than 200 lbs. per square inch of section.

The breaking strength of the briquetts at 28 days after gauging shall show an increase on the breaking strength at 7 days and shall be not less than the number of pounds per square inch of section arrived at from the following formula :—

$$\text{Breaking strength at 7 days} + \frac{10{,}000 \text{ lbs.}}{\text{Breaking strength at 7 days.}}$$

The standard sand shall be obtained from Leighton Buzzard, be thoroughly washed and dried, and shall pass through a sieve of 20 × 20 meshes per square inch, and be retained on a sieve of 30 × 30 meshes per square inch. The sieves shall be prepared from wire-cloth, the wires being ·0164 inch and ·0108 inch in diameter respectively. The wire-cloth shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

13. Tests for setting time.

Unless a specially slow setting cement be required of which the minimum time of setting has been specified, the cement shall be of one of three distinct gradations of time of setting, designated as "Quick," "Medium," and "Slow."

Quick.—Initial setting time not less than two minutes.
Final setting time not less than ten minutes, nor more than thirty minutes.

Medium.—Initial setting time not less than ten minutes.
Final setting time not less than thirty minutes, nor more than three hours.

Slow.—Initial setting time not less than thirty minutes.
Final setting time not less than three hours, nor more than seven hours

The initial and final setting times of the cement shall be determined by means of the Vicat needle apparatus shown on Plate 3.

For the purpose of carrying out the tests, a test block shall be made as follows :—

Neat cement shall be gauged in the manner and under the conditions referred to in clause 11, and the gauging shall be completed before signs of setting occur. The test block shall then be made by filling the cement gauged as above into the Vicat mould shown at E, Plate 3, the mould resting upon a non-porous plate. The mould shall be completely filled, and the surface of the test block shall then be smoothed off level with the top of the mould.

For the determination of the initial setting time the test block confined in the mould and resting on the plate shall be placed under the rod bearing the needle, when the latter shall then be lowered gently into contact with the surface of the test block and quickly released, and allowed to sink into the same ? This process shall be repeated until the needle, when brought into contact with the test block and released as above described, does not pierce it completely. The period elapsing between the time when

the cement is filled into the mould and the time at which the needle ceases to pierce the test block completely shall be the initial setting time above referred to.

For the determination of the final setting time the needle (C) of the Vicat apparatus shall be replaced by the needle (F), shown separately on Plate 10. The cement shall be considered as finally set when, upon applying the needle gently to the surface of the test block, the needle makes an impression thereon, while the attachment shown in the figure on Plate 3 fails to do so In the event of a scum forming on the surface of the test block, the underside of the test block may be used for determining the final set.

14. Test for soundness.

The cement shall be tested for soundness by the Le Chatelier method. The apparatus for conducting the Le Chatelier test is shown on Plate 11. The moulds shall be kept in good condition, having the jaws not more than 0·5 mm. apart.

In conducting the test the mould shall be placed upon a small piece of glass and filled with cement gauged in the manner and under the conditions referred to in clause 11, care being taken to keep the edges of the mould gently together whilst this operation is being performed. The mould shall then be covered with another glass plate, upon which a small weight shall be placed, and the whole shall then be immediately submerged in water at a temperature of 58 to 64 degrees Fahrenheit, and left there for 24 hours.

The distance separating the indicator points shall then be measured, and the mould again submerged in water at 58 to 64 degrees Fahrenheit, which shall be brought to boiling point in 25 to 30 minutes and kept boiling for six hours. The mould shall then be removed from the water and allowed to cool and the distance between the points again measured; the difference between the two measurements represents the expansion of the cement. When the sample has been aerated for 24 hours in the manner described in clause 7, the expansion as above determined shall not exceed 10 millimetres. In the event of the cement failing to comply with this test a further test shall be made from another portion of the same sample after it shall have been aerated for a total period of 7 days in the manner before described, when the expansion determined as above shall not exceed 5 mm.

15. Non-compliance with tests.

Any cement which does not comply with the whole of the tests and analyses hereinbefore specified may be rejected as not complying with this Specification.

16. Copies of Vendor's tests and analyses, etc.

The Vendor shall, if required, furnish free of cost a copy of any document in his possession showing the result of any tests or analysis made for him or for any other person of any cement sold or offered for sale to the Purchaser or of the lot from which the cement so told or offered for sale has been or is to be taken, and shall, if required, furnish free of cost a certificate that the cement so sold or offered for sale has been tested and analysed, and that such tests and analysis comply in all respects with this Specification, but the furnishing of such copies of documents or the giving of such certificate shall not preclude the Purchaser from rejecting any cement which does not comply with this Specification.

17. Delivery.

Cement shall be delivered in bags, barrels or other packages, bearing the Manufacturer's name. A Purchaser desiring to have the cement delivered in bags, barrels or packages sealed or of any particular size must so specify at the time of ordering.

APPENDIX B.

LIST OF INDIAN TREES PREPARED BY COLONEL A. M. LANG, R. E.

In the following list the trees marked* grow in the Punjab and United Provinces. The numbers entered below those in the columns W to P (such as 17, 126, etc. under Acacia arabica) refer to the vernacular names in the supplementary list of local synonyms which follows this list.

The letters denoting weight and constants of strength and elasticity have the precise meanings explained below.

W = weight in *lbs.* of a *cubic foot* of seasoned wood.

E_d = Coefficient of elasticity applicable to Barlow's formula $bd^3 = \dfrac{W \times L^3}{E_d \times \delta}$.

Where L = length in *feet* of beam *supported* at both ends.

b and *d* = breadth and depth in *inches*.

w = load in *lbs.* at *centre*

δ = deflection in *inches* at centre [the safe limit of which for timber is $\frac{1}{480}$ of the clear span].

F_t = tensile strength in *lbs.* per square inch.

P = breaking weight in *lbs.* at *centre* applicable to the formula $bd^2 = \dfrac{WL}{P}$.

No.	Name	W	Ed	Ft	p	
1	**Abies Smithiana.** (*Coniferæ*). 247.					A lofty spruce fir of the N.-W. Himalaya, dark and sombre, yet graceful with its symmetrical form and pendulous habit It furnishes a white wood, easily split into planks; but not esteemed as either strong or durable. It is used as "shingle" for roof coverings.
2	*** Acacia Arabica** (*Leguminosæ*). 17, 126, 139, 162, 199	54	4186 4111	16815	884 876	This well-known, yellow-flowered, "babul" tree is widely distributed. It grows rapidly, requiring no water, and thriving on poor soil, dry arid plains, black cotton soil, etc. It seldom attains a height of 40 feet, or 4 feet in girth: its wood is close-grained and tough, of a pale red colour inclining to brown. It can never be had of large size, and is generally crooked. Used for spokes, naves and felloes of wheels, ploughshares, tent pegs.
3	*** Acacia Catechu** 46, 140, 271, 337.	56 to 60				A widely distributed tree, with a heavy, close-grained and brownish-red wood, of great strength and durability; employed for posts and uprights of houses, spear and sword handles, ploughs, pins and treenails of cart wheels. But the tree is rarely available for timber, being used for the extraction of *catechu*.
4	*** Acacia elata.** 71, 267.	39	2926	9518	695	A handsome, lofty tree, suitable for avenues, and furnishing logs 20 to 80 feet long and from 5 to 6 feet in girth Wood red, hard, strong and very durable. Used in posts for buildings and in cabinet work.
5	**Acacia leucophlæa** 139, 294, 382.	55	4086	16288	861	This very thorny, white-barked "kikar" is found in most parts of India, and its timber in characteristics much resembles that of *A. arabica*, and is used for the same purposes.
6	*** Acacia modesta.** 224.					The *Phulahi* is a common small, and characteristic tree of many parts of the Punjab, (as the Jullundur and Hoshiarpur districts). It is well worthy of cultivation for timber in dry sandy tracts of country, and furnishes very hard and tough timber, fitted for making mills, etc.

No.	W	Ed	Ft	p

7 *** Acacia speciosa.**

W	Ed	Ft	p
55	3502		793
	3532		532

27, 135, 278, 324.

The "sirris" is a common tree throughout India, and with its rapid growth, its large head of handsome foliage and sweet-scented flowers, is a good avenue tree. It grows to 40 or 50 feet in height and 5 to 6 feet in girth ; the wood is said by some writers to be hard, strong and durable, never warping or cracking, and to be used by the natives of South India for naves of wheels, pestles and mortars, and for many other purposes ; but in Northern India it is held to be brittle, and fit only for such purposes as box planks and for firewood.

8 *** Acacia stipulata.**

W	Ed	Ft	p
50	4474	21416	823

268.

This unarmed, pink-flowered acacia, one of the largest of the genus, is found from Dehra Dun to Travancore, and in Assam and Burma. It furnishes large, strong, compact, stiff, fibrous, coarse-grained, reddish-brown timber, well suited for wheel naves, furniture and house-building.

9 **Adenanthera pavonina.**
(*Leguminosæ*).

W	Ed	Ft	p
56	3108	17846	863
55			1060

248, 353, 345.

A large and handsome tree found in most of the forests of India and Burma, though the timber does not enter the market in large quantities. The wood is strong, but not stiff, hard and durable, tolerably close and even-grained, and stands a good polish. When fresh cut it is of beautiful red coral colour, with a fragrance somewhat resembling "sandal" wood ; after exposure it becomes purple, like rose wood. It is used sometimes as sandal wood, and is adapted for cabinet-making purposes.

10 **Ailanthus excelsa.**
(*Simarubaceæ*).
217, 222.

This tree grows in Southern India, and is found also in Oudh and other parts of Northern India, apparently as an introduced tree. It is a remarkably rapidly growing tree and consequently, though useful for avenues, etc, where shade-giving trees are required to grow quickly, it does not furnish timber of any value. The wood is white, light and not durable, and is used for scabbards, etc.

11 **Albizzia elata.**
(*Leguminosæ*).

W	Ed	Ft	p
42 to 55			

268.

Abundant on the banks of rivers in the Burmese plains. It is used by the Burmese for bridges and house posts; it has a large proportion of sap-wood, but the heart-wood is hard and durable ; and in Dr. Brandis' opinion the wood may eventually become a valuable article of trade.

12 **Albizzia stipulata.**

W	Ed	Ft	p
66			

36

Grows in forests on elevated ground in Burma ; it has beautifully streaked brown heart-wood, which is much prized for cart wheels and bells for cattle.

13 **Albizzia** *sp*.

W	Ed	Ft	p
46	4123	19268	855

147.

"Kokoh" is the Burmese name for an *Albizzia*, the wood of which is very much valued by the natives for cart wheels, oil presses and canoes. It is a lofty tree, often having 60 feet of trunk before the first branche is thrown off.

14 **Artocarpus hirsuta**
(*Artocarpaceæ*).

W	Ed	Ft	p
40	3905	15070	744

10, 118, 307.

This large, handsome, shady tree grows in Burma and South-east India. It yields the "anjely" wood of commerce, especially esteemed as a timber bearing submersion in water. It is durable, and is much sought after for dock-yards as second only to teak for ship-building: it is also used for house-building, canoes, etc.

15 **[3] Artocarpus integrifolia.**

W	Ed	Ft	p
44	4030	16420	788

108, 130, 167, 208, 226.

The common "jack fruit" tree, is of rapid growth, and reaches a very large size. It is found all over India, and is esteemed both for its fruit and timber, and with its abundant dark foliage and numerous pendant fruit is a handsome object. The wood when dry is brittle, and has a coarse and crooked grain. It is, however, suitable for some kinds of house carpentry and joinery; tables, musical instruments, cabinet and marquetry work, etc. The wood when first cut is yellow, afterwards changing to various shades of brown.

No.	Name	W	Ed	Ft	p	Pages	Description
16	*Artocarpus Lakoocha	40				41, 170, 171.	The "monkey jack" with its orange-coloured fruit is found usually as a cultivated plant near houses in India and Burma. The wood is used in the latter country for canoes ; the fruit is eaten, and a yellow dye is obtained from the root.
17	Artocarpus Mollis	30				316	An immense tree on the hills of British Burma, having an average length of trunk to the first branch, of 80 feet and girth of 12 feet, 6 feet above ground. The timber is used for canoes and cart wheels.
18	*Azadirachta indica. (*Meliaceæ*).	50	3183 2672	17450	720 752	197, 301, 326, 333.	The beautiful and well-known "neem" tree is common throughout India and Burma, and is much esteemed for ornament and shade. It grows in the stoniest soil. The wood is hard, fibrous and durable, except from attacks of insects ; is of a reddish brown colour : and is used by the natives for agricultural and building purposes. It is difficult to work, but is worthy of attention for ornamental woodwork. Long beams are seldom obtainable ; but the short thick planks are in much request for doors and door frames of native houses on account of the fragrant odour of the wood.
19	*Bambusa. (*Graminaceæ*).	(Plains) (Hills)	2801 5735		686 970	24, 26, 190.	There are many distinct species of bamboo, all of which are applied to numerous useful purposes : bridge-building, scaffolding, ladders, water pipes, rafts, roofing chairs, beds, etc. They are of all sizes up to 60 feet in length and eight inches diameter. The bamboo is the most generally useful of all the vegetable products of India, and experiments seem to show that it is stronger than any other Indian wood. It is *Endogenous*, being in reality a gigantic grass.
20	Barringtonia acutangula. (*Myrtaceæ*).	56	4006	19560	863	1, 74, 168.	A large tree common to India generally and Burma : 30 feet high ; 4 feet in girth ; flowers red. The wood is of a beautiful red colour, tough and strong, with a fine grain and susceptible of good polish. It is used in making carts and is in great request by cabinet makers.
21	Barringtonia racemosa	56	3845	17705	819	6.	This tree is a native of Southern India, the Moluccas, etc., and when in blossom is showy with its large rose-coloured flowers. The wood is lighter coloured, and close-grained but of less strength than that of the last named species. It is used for house-building and cart framing, and has been employed for railway sleepers.
22	*Bassia latifolia. (*Sapotaceæ*).	66	3420	20070	760	106, 175.	The "Mahwah," a well-known Indian tree, is in most districts preserved for its large fleshy flowers which are eaten and used in distilling arrack. The wood is, however, sometimes used for doors and windows and furniture, but it is said to be eagerly devoured by white-ants.
23	Bassia longifolia.	60	3174	15070	730	183.	A common tree in Southern and Central India esteemed for its edible flower and fruit and the oil extracted from its seeds. For these reasons it is not commonly considered a timber tree, though in Malabar, where it attains a large size, it is used for spars, and is considered nearly equal to teak, though smaller.
24	Bauhinia variegata. (*Leguminosæ*).					154.	This and other species of the genus are valuable, not for their timber but as ornamental trees for avenues, etc., having beautiful conspicuous flowers ; the centre wood is hard and dark like ebony, but seldom large enough for building purposes.
25	*Bauhinia Vahlii					176.	Some species of Bauhinia are scandent plants ; and among the largest of these is the "Elephant creeper" (a name applied also to *Argyreia nervosa*) which destroys hundreds of valuable timber trees in the sal forests of Northern India, where one of the most arduous duties of the Forest department is the eradication of these gigantic creepers, whose cable-like stems form festoons from tree to tree.

No.	W	Ed	Ft	p

26 **Berrya Ammonilla.**
(Tiliaceæ).
| 50 | 3836 | 26704 | 784 |
264, 809, 317.

"Trincomallie" wood is indigenous to Ceylon, whence large quantities are annually imported into India; but the tree has also been introduced into South India. It is the most valuable wood in Ceylon for naval purposes; and furnishes the material of the Madras Masula boats; it is considered the best wood for capstan bars, cross-trees and fishes for masts. It is light, strong and flexible, and takes the place of *Ash* in Southern India for shafts, helves, etc.

27 **Betula Bhojpattra.**
(Betulaceæ).
30.

This is the best known of the Himalayan birches, and is valuable for its abundant loose bark used as paper, and for lining baskets, *hukah* tubes, etc; also as a layer over the planking for roof to receive the tiles or terrace in the native houses in Tibet, etc.

28 **Bignonia chelonoides.**
(Bignoniacæ).
| 48 | 2804 | 16657 | 642 |
202.

This tree with its large fragrant, brownish orange-coloured flowers is considered sacred by the Hindus, and is consequently not largely available as timber. The wood is highly coloured, orange yellow, hard and durable: a good fancy wood and suitable for house-building. It is found in Southern India and Assam.

29 **Bignonia stipulata.**
| 64 | 5033 | 28998 | 1386 |
180, 223.

A flowering tree of the Tenasserim forests which furnishes logs 18 feet in length and 4 feet in girth, with strong, fibrous elastic timber resembling teak, used in house-building and for bows, and spear handles. This is one of the strongest, densest and most valuable of the Burman woods.

30 ***Bombax heptaphyllum.**
(Bombaceæ).
| | 2225 | 6951 | 678 |
62, 270.

The large and stately red "Cotton" tree is widely distributed throughout India and Burma. Its light loose-grained wood is valueless as timber, but it is extensively used for packing cases, tea chests and camel trunks; and as it does not rot in water, it is useful for stakes in canal banks, etc. It is a rapidly-growing tree, and long planks 3 feet in width can be obtained from old trees.

31 **Borassus flabelliformis.**
(Palmaceæ).
| 65 | 4904 | 11898 | 944 |
96, 207.

The "Palmyra palm" is inferior only to the Date and Cocoanut palms to the natives of Asia. The sap furnishes toddy, the seeds are eaten, the leaves are used for thatching, mats, baskets and for writing upon; while the timber, which is very durable and of great strength to sustain cross-strain, is used for rafters, joists and battens. The trees have, however, to obtain a considerable age before they are fit for timber.

32 **Briedelia spinosa.**
(Euphorbiaceæ).
| 60 | 4132 | 14801 | 892 |
149, 189.

A large tree of Central and Southern India, with strong, tough, durable, close-grained wood, of a copper colour, which however is not easily worked. It is employed by the natives for cart building and house beams: and is also used for railway sleepers. It lasts well under water, and is consequently used for well curbs.

33 ***Butea frondosa.**
(Leguminosæ).
67, 234, 237, 238, 239.

The "*dhâk*" tree, with its brilliant scarlet blossoms, is widely distributed throughout India, and often forms large tracts of low forest. The wood is generally small or gnarled, and used only for firewood. In Guzerat, however, it is extensively used for house purposes, and deemed durable and strong. The flowers give a bright yellow dye.

34 **Buxus Nepalensis.**
(Euphorbiaceæ).
87, 275.

The Himalayan box, which is found in the North-West Himalayas, but nowhere abundantly, furnishes a very valuable wood for wood engraving; but not equal in closeness and grain or hardness to "Turkey" or European box. It can, however, be used for all but the finest wood engraving, and was largely employed for this purpose at the Thomason College at Roorkee.

No.		W	Ed	Ft	p	
35	**Buttneria. sp.** (*Buttneriaceæ*). 215.	63	4284	26571	1012	This tree is abundant in Tenasserim, and furnishes a wood of great elasticity and strength, invaluable for gun carriages. It is used by the Burmese for axles, cart poles and spear handles.
36	**Cæsalpinia Sappan.** (*Leguminosæ*) 38, 242, 268, 292.	60	4790	22578	1540	This tree is widely distributed through South-Eastern Asia, and is an important article of commerce; but from its value as a dye-wood it is not available as timber, though it is admirably adapted for ornamental work, being of a beautiful "flame" colour, with a smooth glassy surface, easily worked, and neither warping nor cracking.
37	**Calamus.** (*Palmaceæ*). 29, 43.					There are many species of this genus, furnishing the rattan canes of commerce, which are used for "caning" chairs, light carriages, etc. To the Engineer they furnish materials for suspension bridges of considerable span; the natives of the Khasia Hills make single spans of 300 feet with these strong and flexible canes.
38	**Calophyllum Angustifolium.** (*Guttiferæ*). 152, 228, 231, 233, 302.	45	2944	15864	612	This is one of the trees furnishing the valuable 'Poon' spars used in ship-building. The trees are becoming scarce on the Malabar Ghats and should be conserved. Drs. Roxburgh, Gibson and Cleghorn concur in stating that *C. Angustifolium* furnishes the *Poon* spars of commerce, but C *Inophyllum* also, as well as *Calysaccion Angustifolia*, *Dillenia pentagyna* and *Sterculia fœtida* also furnish timber often termed *Poon*.
39	**Calophyllum Longifolium.** 228, 232, 283, 302.	45	3491	16388	546	A tree of Pegu and Moulmein, furnishing a red wood, excellent for masts, helves, etc., and also (when well cleaned and polished) for furniture; but it does not appear to be abundant. The timber of this tree is sometimes termed "Red Poon."
40	***Careya arborea.** (*Barringtoniaceæ*). 23, 127, 143, 158, 204.	50 56	3255	14803	870 675	This tree grows in most parts of India of a good size, and furnishes a tenacious and durable wood which admits of a fine polish. It does not, however, appear to be much used as timber, except in Pegu, where it grows to a very large size, and is the chief material of which the carts of the country are made and the red wood is esteemed equivalent to mahogany. It is useful as a shady avenue tree.
41	***Casuarina muricata.** (*Casuarinaceæ*). 45.	55	4474	20887	920	This fir-like tree, imported from Tenasserim, is common now in most parts of India, in avenues, gardens, etc. It thrives best in sandy tracts, especially near the sea. It yields a strong, fibrous and stiff timber of a reddish brown colour. It grows with great rapidity and is admirably fitted for stakes in canals, etc.
42	***Cathartocarpus Fistula.** (*Leguminosæ*). 9, 87, 124, 287.	41	3153	17705	846	This is an ornamental tree for avenues and gardens, scarcely to be surpassed in beauty when covered with scented masses of yellow pendulous blossom. It is found all over Southern Asia, but generally as a small tree whose close-grained, mottled, dark-brown wood is suited for furniture; in Malabar, however, it grows large enough to be used for spars of native boats.
43	***Cedrela Toona.** (*Cedrelaceæ*). 305, 311, 312.	31	2684 3568	9000	560	The "Toon" is a valuable tree found throughout India, and yields a wood extensively used by furniture and cabinet-makers, which though not strong, is light, aromatic, close-grained, beautifully veined, easily worked, and susceptible of a high polish. It is an admirable avenue tree with handsome evergreen foliage.
44	**Cedrus Deodara.** (*Coniferæ*). 66, 136, 137.		3565 3205 3925		456 586 517 655	This handsome tree of the North-West Himalaya furnishes a fragrant, almost imperishable, timber of great value in roof and bridge-building and for railway sleepers. It is considered to be identical with the cedar of Lebanon. It is the most valuable timber of the Himalayas, where it grows in large forests. The appearance of the tree and value of the timber vary much with the soil and aspect of the place where it is grown.

No. | W | Ed | Ft | p |

45 **Chickrsasia tabularis** (*Cedrelaceæ*).
| 42 | 2876 | 9943 | 614 |
4, 52, 53, 343.

This is one of the trees named in commerce "*Chittagong*" wood, though occurring also in Burma, Southern India and Eastern Bengal. The wood resembles "Toon" in appearance and aroma, but is more strong and tough, though very liable to warp; it is used as "Mahogany" by cabinet-makers.

46 **Chloroxylon Swietenia** (*Cedrelaceæ*).
| 60 | 4163 | 11369 | 870 |
31, 72, 265, 334, 335.

This tree of Southern India and Ceylon produces a beautiful yellow wood somewhat resembling "box" and known as *Satin wood;* it is well adapted for ornamental decoration, and for picture frames is nearly equal to American maple. Logs up to 18 feet long and 6 feet in girth are obtainable in Madras. It is a hard and durable wood, used for posts and rafters, agricultural implements and wheel naves.

47 **Cocos nucifera.** (*Palmaceæ*).
| 70 | 3605 | 9150 | 608 |
58, 193, 194, 296.

The "Cocoanut palm" widely distributed through Southern India and the Eastern Archipelago is one of the most valuable of trees, chiefly esteemed for its nut, but furnishing also very hard and durable wood, fitted for ridge poles, rafters, battens, posts, pipes, boats, etc. It grows from 40 to 100 feet high and 2 to 4 feet mean girth, and thrives best near the sea.

48 **Connarus speciosa.** (*Connaraceæ*).
19, 119.

A large tree plentiful in the Burmese forests, with heavy, strong, white timber, adapted to every purpose of house-building.

49 **Conocarpus acuminata.** (*Combretaceæ*)
| 59 | 4352 | 20623 | 880 |
213, 344.

A large timber tree of Southern India and Burma, where it reaches a height of 80 feet before the first branch, and a girth of 12 feet at 6 feet above ground. The heart-wood is reddish-brown, hard and durable, used for house and cart-building. If exposed to water it soon decays.

50 ***Conocarpus latifolia.**
| 65 | 5033 | 21155 | 1220 |
20, 21, 70, 308, 331.

This is an equally large tree as the preceding, but it is more widely distributed, occurring in Northern India and in Dehra Dun. It furnishes a hard, durable, chocolate-coloured wood, very strong in sustaining cross strain. In Nagpore 20,000 axletrees are annually made from this wood. It is well suited for carriage shafts.

51 **Cupressus torulosa** (*Coniferæ*)
65, 172.

This is a handsome lofty tree of the North-West Himalaya; but is not at all abundant, and being esteemed as sacred [and termed "dewadara" (deodar) or "god timber" in some Hill States] it is not felled or made generally available as timber, though very well suited for this purpose.

52 **Dalbergia latifolia.** (*Leguminosæ*).
| 50 | 4053 | 20283 | 912 |
32, 34, 79, 276, 341.

This tree is distributed throughout India, but reaches perfection on the Malabar coast It is perhaps the most valuable tree of the Madras Presidency, furnishing the well-known Malabar blackwood. The trunk sometimes measures 15 feet in girth, and planks 4 feet broad are often procurable after the outside white wood has been removed. It is used for all sorts of furniture, and is specially valued in gun-carriage manufacture.

53 ***Dalbergia Oojeinensis.**
261, 303.

A tree 30 feet high, growing in the valleys of the Himalaya, in Oudh, on the Godavery, and in Bombay. The centre timber is dark, of great strength and toughness, especially adapted for cart-wheels and ploughs.

54 ***Dalbergia Sissu.**
| 50 | 4022 | 21257 | 807 |
| | 3516 | 12072 | 706 |
266, 278, 279.

There is scarcely a tree in India which deserves more attention than the *Sissu*, taking into account its beauty and uses, and its rapid growth in every soil. It is said to attain perfection in 28 years. It is widely spread through Northern and Central India, and is more used than any tree for avenues along roads and canals, and for planting in Cantonments. It furnishes the Bengal Gun-carriage Agencies with their best timber, and is the best of all Indian woods for joiner's work, tables, chairs and furniture.

No.	W	Ed	Ft	p	
55 **Dillenia Pentagyna.** (*Dilleniaceæ*). 33, 128, 228, 231, 340.	70	3650	17053	907	A stately and valuable forest tree of Southern India and Burma, furnishing some of the *Poon* spars of commerce. The wood is used in house and ship-building, being close-grained, tough, durable (even under ground), of a reddish-brown colour, not easily worked, and subject to warp and crack.
56 * **Dillenia speciosa.** 54, 216, 297, 323, 346.	45	3355	12691	721	The *Chulta* is a large and ornamental tree of India and Burma, with large fragrant white flowers, edible fruit, light and strong, light brown wood of the same general characteristics with the preceding tree. It is used in house-building and for gun stocks.
57 **Diospyros Ebenum.** (*Ebenaceæ*). 2, 73, 288, 318.					The true *Ebony* tree grows in Ceylon and Southern India. The heart-wood is deep black, the outer wood is white; with advancing age the black wood increases. It is much affected by the weather, so that it is seldom used, except in veneer and delicate and costly cabinet work.
58 **Diospyros hirsuta.** 42, 60.	60	4296	19830	757	A middle-sized tree of Ceylon and Coromandel, furnishing one of the *Calamander* woods of commerce, of a chocolate colour, with black streaks and marks, esteemed for ornamental purposes; scarce and valuable. Obtainable in logs 12 feet long, 4 feet in girth.
59 **Diospyros Melanoxylon.** 73, 295, 320, 321.	81	5058	15873	1180	This is a very large tree of South India and Pégu, furnishing a valuable wood for inlaying and ornamental turnery, the sap-wood white, the heart-wood even-grained, heavy, close and black, standing a high polish.
60 **Diospyros tomentosa.** 295, 319.					This is the North Indian representative of the ebony-producing southern forms of Diospyros, occurring in Northern Bengal, Oudh, etc., a tall, elegant tree, furnishing a hard and heavy black-wood. The young trees are extensively felled by the natives as cart axles, for which they are well suited from their toughness and strength.
61 **Dipterocarpus alatus.** (*Dipterocarpaceæ*). 5, 131, 339.	45	3247	18781	750	A magnificent forest tree of Pegu and the Straits, rising 250 feet in height and 100 feet to the first branch. The timber is excellent for every purpose of house-building, but if exposed to moisture is not durable; it is hard and coarse-grained, with a powerful odour, and of light brown colour. It furnishes *wood oil*.
62 **Dipterocarpus turbinatus.** 131, 310, 339.	45 49	3355	15070	762 807	This is another lofty wood oil tree of Assam and Burma and the Andamans, with a coarse-grained timber of a light brown colour, not easily worked, and not durable. It is used by the natives for house-building, in sawn planks, which will not stand exposure and moisture.
63 * **Emblica officinalis.** (*Euphorbiaceæ*). 6, 11, 198.	46	2270	16964	562	The tree, producing the *Myrobalan* fruit, is distributed throughout India, furnishing a hard and durable wood, used for gun-stocks, furniture, boxes and veneering and turning; it is suitable for well-curbs, as it does not decay under water.
64 * **Erythrina indica.** (*Leguminosæ*). 59, 82, 214, 241.					A common tree throughout India and Burma, with a profusion of brilliant scarlet blossoms, whence it is called the "Coral" tree; it furnishes a soft, white, easily worked wood, being light, but of no strength, and eagerly attacked by white-ants. It is used for scabbards, toys, light boxes and trays, etc. It grows very quickly from cuttings.
65 * **Eucalyptus.** (*Myrtaceæ*).					This is not an Indian genus, but many species are now being naturalized in both the hills and plains of India, imported from Australia. Sufficient time has not yet elapsed to establish the value of the "*Blue gum*" and other Eucalypti when grown in India.

No.	W	Ed	Ft	p	

66 * Feronia Elephantum.
(*Aurantiaceæ*).
| 50 | 3248 | 13909 | 645 |
123, 166, 328, 330, 338.

The tall *Wood apple* tree is widely diffused throughout India, both wild and in gardens and groves; the pulp of the large, hard shelled fruit is eaten, and the bark furnishes a large quantity of clear white gum known as "East India Gum Arabic." It has a yellow-coloured, hard and compact wood, used by the natives in house and cart-building, and in some places employed as railway sleepers.

67 * Ficus elastica.
(*Moraceæ*).
44, 105, 134.

The Caoutchouc fig tree grows on the hills of Assam and Sylhet, but is to be found as an imported tree in other parts of India. The milky juice is extracted by incisions across the bark down to the wood: 50 ozs. of the juice furnish 50 ozs. of Caoutchouc.

68 * Ficus glomerata.
| 40 | 2113 | 12691 | 588 |
| | 2096 | | |
15, 86, 182.

The *Gooler* is a wide-spreading shady tree, producing great numbers of small red figs growing in clusters on the branches. The wood is light, tough, coarse-grained and brittle. It is used for door panels and being very durable under water, for well-curbs.

69 * Ficus indica.
| 36 | 2876 | 9157 | 600 |
39, 40

The well-known "Banyan" or "Bur" is one of the commonest trees of India. Its wood is brown-coloured, light, brittle and coarse-grained, neither strong or durable (except under water, for which cause it is used for well-curbs). The wood, however, of its pendent aerial roots, is strong and tough, and used for yokes, tent poles, etc.

70 * Ficus religiosa
| 34 | 2454 | 7535 | 684 |
| | 2371 | | 458 |
219.

The *Pipul* is as widely spread and well-known as the Banyan, and with it is planted near temples and tombs and in sacred groves. The wood is similar in appearance, characteristics and uses to that of the Banyan.

71 Gmelina arborea.
(*Verbenaceæ.*)
| 35 | 2132 | | |
84, 89, 159, 269.

A large forest tree of Central and Southern India and Burma: a suitable tree for avenues from its size, straightness and handsome flowers. It has a pale yellow wood, light, easily worked, not shrinking or warping, strong and durable, especially under water; it is, however, readily attacked by white-ants; used for furniture, carriage panels, palkis, etc. In Burma used for posts and house-building generally.

72 (*a*) * Grewia elastica.
(*b*) Grewia tiliæfolia.
(*Tiliaceæ.*)
| 34 | 2876 | 17450 | 565 |
68, 69, 254, 298.

In some parts of India these trees are said to reach a large size, but the wood generally is procured in small scantlings, suitable for spear shafts, carriage and dooly poles, bows and tool handles, for which it is admirably adapted, being light, soft, flexible and fibrous, resembling lance wood or hickory.

73 Guatteria longifolia.
(*Anonaceæ.*)
| 37 | 2860 | 14720 | 547 |
14.

This handsome, erect tree with beautiful foliage and dark shade, is much grown as an ornamental avenue tree in Southern India. The wood is very light and flexible, but is not used except for drum cylinders.

74 Hardwickia binata.
(*Leguminosæ*).
| 85 | 4579 | 12016 | 942 |
16, 195.

An elegant, tall and erect tree of Central and Southern India, furnishing a red or dark coloured, very hard, very strong and heavy wood, useful for posts, pillars and piles: and excellent also for ornamental turnery.

75 Heritiera minor.
(*Sterculiaceæ.*)
64	3775	29112	816
	4677		1312
			925
129, 283.

This peculiar, gloomy looking tree, known in Bengal as the "Sundri," grows on tracts occasionally inundated by the tides in Tenasserim and the Gangetic Delta (giving their name to the Sunderbunds). It is the toughest wood that has been tested in India, and stands without a rival in strength, and is used for piles, naves, felloes, spokes and carriage shafts and poles. It is, however, a perishable wood, and shrinks much in seasoning.

No.	W	Ed	Ft	p	

76 Hopea odorata.
(*Dipteraceæ.*)

58	3660	22209	800
45			706

304.

One of the finest timber trees of British Burma, sometimes reaching 80 feet in height to the first branch, and 12 feet in girth; a large boat of 8 feet beam and carrying 4 tons being sometimes made of a single scooped-out trunk. The wood is close, even grained, of a light brown colour.

77 * Inga lucida.
(*Leguminosæ*).
107, 290.

A very fine and rapid growing timber tree from Southern India, Burma, Assam, Nepal, etc., growing to a great height, with sweet-scented blossoms and magnificent, shady foliage; well suited for avenues. The heart-wood is black, and is termed *Iron wood* in Burma.

78 Inga xylocarpa.

58	4263	16657	836

78, 80, 107, 109, 110, 148, 221, 245.

This valuable timber tree, known as the *Iron wood* of Arracan, is found throughout Southern India and Burma, wood of very superior quality, heavy, hard, close-grained and durable, and of a very dark red colour: it is, however, not easily worked and resists nails. It is extensively used for bridge-building, posts, piles, etc., and is a good wood for sleepers, lasting (when judiciously selected and thoroughly seasoned) for six years.

79 Juglans Regia.
(*Juglandaceæ*)
6, 336.

The *Walnut* is abundant in the villages of the N.-W. Himalaya, and its beautiful wood is used for all sorts of furniture and cabinet work in the bazars of the hill stations.

80 *Lagerstrœmia Reginæ.
(*Lythraceæ.*)

40	3665	15338	637
41			612

112, 116, 138, 218, 246

This is a most beautiful flowering tree from South India, Burma and Assam, but introduced into the gardens of North India for the beauty of its luxuriant purple blossoms. In Burma it grows to a large tree, and the wood is used more extensively than any other, except teak, for boat, cart and house-building, and in the Madras Gun-carriage manufactory, for felloes, naves, framing of wagons, etc.

81 *Mangifera indica.
(*Terebinthaceæ.*)

42	3710	9518	632
	3120	7702	560

7, 174, 177, 178, 181, 299

The *Mango* is generally diffused over all the warmer parts of Asia and is much esteemed for its fruit. Its wood, however, is of inferior quality, coarse and open-grained, of deep grey colour, decaying if exposed to wet, and greedily eaten by white-ants. It is, however, largely used, being plentiful and cheap, for common doors and door-posts, boards and furniture, and also for firewood. It should never be used for *beams*, as it is liable to snap off short.

82 *Melanorhœa usitatissima.
(*Anacardiaceæ.*)

61	3016		514

306, 327.

The *Varnish* tree of Burma forms large forests in conjunction with teak and sál, and furnishes a dark-red, hard, heavy, close and even-grained and durable (but brittle) timber, useful for helves, sheave blocks, machinery, railway sleepers, etc.

83 *Melia Azedarach.
(*Meliaceæ*).

30	2516	14277	596

35, 322.

The "Persian Lilac" of India which grows throughout China, India, Syria, etc., is ornamental when in full foliage, and covered with sweet-scented lilac flowers: but it is deciduous and bare of leaves for many months, showing then only its bunches of yellow "beads"; so that it is not altogether desirable as an avenue tree, though very much planted for this purpose. The soft, red-coloured, loose-textured wood (resembling in appearance cedar) is used only for light furniture.

84 *Michelia Champaca.
(*Magnoliaceæ.*)

42			

55, 56, 57, 259.

A fine timber tree with handsome foliage and flowers. In the Dehra Dun it reaches 16 feet in girth. In Mysore trees measuring 50 feet in girth, 3 feet above ground level are found, and slabs 6 feet in breadth can be obtained; as the wood takes a beautiful polish, it makes handsome tables, and is of a rich brown colour.

No. | W | E_d | F_t | p |

85 *Millingtonia Hortensis. (*Bignoniaceæ*). 61.

A very handsome tree for avenues; tall and straight, with graceful foliage and fragrant white flowers. It grows very rapidly, but is not long lived, and is easily injured by storms. The bark is soft and spongy; the wood is white, fine and close-grained, but of little use.

86 *Mimusops Elengi. (*Sapotaceæ*). | 61 | 3653 | 11369 | 632 | 22, 186, 188, 229

This is an ornamental, more than a useful tree, grown in gardens and avenues throughout India and Burma for the beauty of its foliage and its fragrant white flowers. The wood is heavy, close and even-grained, of a pink colour, standing a good polish, and is used for cabinet-making purposes and ordinary house-building.

87 Mimusops hexandra. | 70 | 3948 | 19036 | 944 | 142, 145, 205.

This tree grows in South India and Guzerat and furnishes wood very similar to the last named; used for similar purposes and for instruments, rulers and other articles of turnery.

88 Mimusops indica. | 48 | 4296 | 23824 | 845 | 206.

This is a valuable tree of South India and Ceylon with a coarse-grained, but strong fibrous, durable wood of a reddish-brown colour; used for house-building and for gun stocks.

89 *Moringa Pterygosperma (*Moringaceæ*). 95, 282.

A handsome tall tree with shady foliage and of rapid growth. The wood is white and soft, and the scrapings from the root form a good substitute for the horse radish.

90 *Morus indica. (*Moraceæ.*) 187, 277, 313.

This species of *Mulberry*, as well as *Morus multicaulis* and *M. nigra* are common in Northern India: in some parts of the Punjab and Oudh, being planted in connection with silk worm rearing. It is also grown in avenues for which, however, it is unsuited, being for many months quite bare of leaves. The wood is yellow, close-grained, very tough, and well suited for turning.

91 Nauclea Cadumba. (*Cinchonaceæ.*) 117, 155, 329

A noble ornamental tree of India and Burma, with orange-coloured flowers: sometimes in the latter country reaching 80 feet in height and 12 feet in girth. It has a hard, deep yellow, loose-grained wood, used for furniture. In the Gwalior bazars it is the commonest building timber, and is much used for rafters on account of cheapness and lightness, but it is obtained there only in small scantlings

92 *Nauclea cordifolia. | 42 | 3052 | 10431 | 664 |
 | | 3467 | | 506 | 97, 102, 170.

This is also a very large tree, with a soft close even-grained wood resembling in appearance box, but light and more easily worked, and very susceptible to alternations of temperature. It is esteemed as an ornamental wood for cabinet purposes.

93 *Nauclea parviflora. | 42 | | | 400 | 97, 122, 225, 342.

A large fine timber tree: with a wood of fine grain, easily worked, used for flooring planks, packing boxes and cabinet purposes; it is much used by the wood carvers of Saharanpur.

94 *Phœnix sylvestris. (*Palmaceæ.*) | 39 | 3313 | 8356 | 512 | 64, 76, 141

This wild "*Date palm*" is common all over India, and is valued for the "*toddy*" extracted from it. The trunks are used for temporary bridges, revetment piling and water conduits. The wood is brown and cross-grained and not very strong

95 Picea Webbiana. (*Coniferæ.*) | 86 | | | | 185, 227, 314.

The *Silver fir*, of the N.-W. Himalaya, grows at high altitudes, 8,000 to 12,000 feet, in dark sombre forests, and reaches from 100 to 200 feet in height, with very short straight lateral branches. The wood is white, soft, easily split and used as shingle for roofing, but is not generally valued as timber.

96 Pinus excelsa. 121, 173.

A handsome lofty pine growing at altitudes of 6,000 to 11,000 feet in the N.-W. Himalaya, and furnishing a resinous wood much used for flambeaux; it is durable and close-grained; much used for burning charcoal in the hills, and also for building.

No.		W	Ed	Ft	p		
97	*Pinus longifolia.		4048 4668 3806 3672		609 735 594 582	50, 51, 285.	The long leaved "Chir" pine is the first of this genus obtained in ascending the Himalaya, growing from 2,000 to 6,000 feet altitude, and being common and light is largely used in house-building. It requires, however, to be protected from the weather, and is suitable for only interior work in houses. It grows well as an imported tree in the plains as low as Meerut.
98	*Pongamia glabra. (*Leguminosæ*).	40	3481	11104	686	133, 164, 210.	This tree grows all over India and Burma and is an excellent avenue tree, reaching in good soil a height of 40 feet, with dense dark green shining foliage all the year round, which, however, is apt to be much disfigured by numberless leaf-mining insects, "blotching" the leaves. The wood is light, tough and fibrous, but not easily worked, yellowish brown in colour, not taking a smooth surface. Solid wheels are made from this wood; it is, however, chiefly used as firewood, and its boughs and leaves as manure.
99	*Prosopis spicigera. (*Leguminosæ*).					114, 272.	A fine timber tree, well suited for dry sandy soils, and furnishing a strong hard tough wood, easily worked. It grows in Mysore and Bombay, but thrives especially in Sindh, where it obtains a large size. It is common also in the Jullundur Doab.
100	*Psidium pomiferum. (*Myrtaceæ*)	47	2676	13106	618	88, 203, 284.	The *Guava* is a well-known fruit tree of South-Eastern Asia. It is a small tree and furnishes a grey, hard, tough, light, very flexible, but not strong wood; which is very close and fine-grained and easily and smoothly worked, so that it is fitted for wood-engraving, and for handles of scientific and other instruments.
101	Pterocarpus Dalbergioides. (*Leguminosæ*).	56 49	4180	19036	864 934	93, 201.	This large and handsome *Padowk* tree is a native of the Andaman and Burmese forests and furnishes a red, mahogany-like timber; prized by the natives above all others for cart-wheels, and extensively used by Government in the construction of ordnance carriages.
102	Pterocarpus Marsupium.	56	4132	19943	868	28, 94, 325.	This large and very beautiful tree is widely diffused and yields one of the most abundant and useful timbers of Southern India, and also the valuable *gum kino*. The wood is light brown, strong and very durable, close-grained, but not easily worked; it is extensively used for cart-framing and house-building, but should be protected from wet; it is also well fitted for railway sleepers.
103	Pterocarpus santalinus.	70	4582	19036	975	249, 253.	The *Red Sandal-wood* tree grows in the forests of South India. Its wood is sold by weight as a dye wood and exported to England. It is heavy, extremely hard, with a fine grain, and is suitable for turnery, being of a dark red colour and taking a good polish.
104	*Pterospermum acerifolium. (*Bytlneriaceæ*).					192.	A lofty, handsome, shady tree, suited for avenues; from South India, Assam and Burma. It has a dark brown wood of great value and as strong as teak, but its durability has not yet been tested.
105	*Putranjiva Roxburghii. (*Euphorbiaceæ*).					113, 161.	A large, shady timber tree with straight, erect trunk and with wood white close-grained, very hard, durable, and suited for turning. It grows along the foot of the Himalaya, and in Oudh, Assam, Sylhet and South India.
106	Quercus— (*a*) „ incana. 25. (*b*) „ dilatata. 184. (*c*) „ semecarpifolia. 163c.						Numerous species of *Oak* are found in the Himalayas, Sylhet, and Malay Peninsula. The three marginally noted from large forests in the N.-W. Himalaya. *Incana* occurring from 5,000 to 9,000 feet, and *semecarpifolia* ascending to 12,000 feet. They are lofty trees, 80 to 100 feet in height, and furnish serviceable timber; in Dr. Cleghorn's opinion some of the best timber we

No.	W	Ed	Ft	p	
	(*Corylaceæ.*)				have. The wood is heavy and for two years or more
			(a)	491	after felling will not float; hence it has not found its
			(c)	670	way to the plains by the rivers, as is the case with the
	200.				pine woods. *Q. semecarpifolia* in colour and grain resembles the English oak.
107	**Rhus acuminata.** 156.				The "Kukkur" of the N.-W. Himalaya furnishes a wood much valued by cabinet-makers for ornamental furniture. Planks 8 × 2½ feet can be obtained from some trees.
108	**Santalum album.** (*Santalaceæ*).				This is the true *Sandal-wood*, and is found abundantly in Mysore. It grows throughout Southern India, Assam,
	58	3481	19461	874	Cochin China, etc., and is sold by weight to be burned
	48, 49, 83, 260, 286.				as a perfume. It is also valued for making work boxes and small articles of ornament, and for wardrobe boxes, etc., where its agreeable odour is a preventive against insects.
109	***Sapindus emarginatus.** (*Sapindaceæ*).				The *Soap-nut* tree is common to India and Burma; a handsome tree 30 feet high and 4 feet girth, furnishing
	64	3965	15495	682	a hard wood, which is not durable or easily worked, and
	151, 243, 250, 280.				is liable to crack if exposed; but is used by natives for posts and door frames: also for fuel. The tree is valued for its nuts or berries used for washing.
110	***Schleichera trijuga.** (*Sapindaceæ*). 92, 146, 150, 153, 165, 244.				A tree of Southern India, producing a red, strong, hard and heavy wood, used for oil presses, sugar crushers and axles. It occurs also in the east of the Punjab. It is a large and common tree in Burma, where excellent solid cart-wheels are formed from it.
111	**Shorea obtusa.** (*Dipteraceæ*)				The *Thee-ya* is a Burmese species of *sal*, producing a heavy and compact wood, closer and darker coloured
	58	3500	20254	730	than ordinary *sal*; used for making carts and oil and
	300				rice mills.
112	***Shorea robusta.**				The *sal* furnishes the best and most extensively used
	55	4209	18243	880	timber in Northern India, and is unquestionably the
		4963	11521	769	most useful known Indian timber for engineering purposes; it is used for roofs and bridges, ship-building
	75, 85, 258, 262.				and house-building, sleepers, etc. The tree grows in forests in the Terai extending along the foot of the Himalaya from the Brahmaputra to the Jumna, and in Burma and Tenasserim. The timber is straight, strong and durable, but seasons very slowly, and is for many years liable to warp and shrink.
113	**Sonneratia apetala** (*Myrtaceæ*). 144, 157.				A large and elegant tree of the Gangetic Delta, Bombay and Rangoon; yields strong, hard, red wood of coarse-grain, used in Calcutta for packing cases for beer and wine, and is also adopted for rough house-building purposes.
114	**Soymida febrifuga.** (*Cedrelaceæ*).				A large forest tree of Central and Southern India, furnishing a bright red and close-grained wood, of great
	66	3986	15070	1024	strength and durability, preferred above all wood by
	251, 252, 274, 281.				the Southern India Hindus for the wood-work of their houses. Though not standing exposure to sun and weather, it never rots underground or in masonry, and is very well suited for palisades and railway sleepers.
115	**Sterculia fœtida.** (*Sterculaceæ*).				A large tree of South India, Ceylon and Burma. In the latter country the trunk is 50 feet to the first
	28	3349	10736	464	branch, and girth 10 feet at 6 feet from ground, but
	90, 115, 220, 231.				the timber is not used there. In Ceylon it is used for house-building, and in Mysore for a variety of purposes taking the place of the true *poon*. The wood is light, tough, open-grained, easily worked, not splitting, nor warping; in colour yellowish white.

No. | W | Ed | Ft | p |

116 *Syzygium Jambolanum. (*Myrtaceæ*).
| 48 | 2746 | 6840 | 600 |
111, 125, 196.

The *Jamoon* is widely diffused through India, and is valued as an avenue tree from its height, handsome foliage and edible plum-like fruit. The brown wood is not very strong or durable, but is used for door and window frames of native houses, though more generally as fuel. It is, however, suitable for well and canal works, being almost indestructible under water.

117 *Tamarindus indica. (*Leguminosæ*).
| 79 | 3145 | 20623 | 864 |
| | 2803 | | 816 |
104, 230, 289.

The *Tamarind* is a very handsome tree for avenues, gardens, etc., of very slow growth, but attaining a great size, and much valued for its fruit. The heart-wood is very hard, close-grained, dark red, very hard to be worked; used for turnery, also for oil presses and sugar crushers, mallets and plane handles; it is a very good brick burning fuel.

118 *Tectona grandis. (*Verbenaceæ*.)
45	3978	15467	814
42			747
		14498	683
169, 255, 257, 291, 293.

The *Teak* furnishes the most useful and durable timber known. It grows in Southern India, Burma, Java, Sumatra, etc. The wood is brown, and when fresh cut is fragrant, very hard yet light, easily worked, and though porous, strong and durable, soon seasoned, and shrinks little; used for every description of house-building, bridges, gun-carriages, ship-building, etc.

119 Terminalia Arjuna. (*Combretaceæ*.)
| 54 | 4094 | 16288 | 820 |
12, 315.

A tree widely diffused: often found in company with teak, and growing to a very large size. It furnishes a dark brown, heavy, very strong wood, suitable for masts and spars, beams and rafters.

120 *Terminalia belerica.
19, 209.

A very large forest tree with a straight trunk and spreading head, and flowers with an offensive smell. It is a very fine looking tree for avenues, but the wood is white and soft and not used in carpentry.

121 *Terminalia Chebula.
| 32 | 3108 | 7563 | 470 |
98, 100, 101, 120, 132.

A beautiful and lofty tree, with horizontal branches, growing in tiers; planted in gardens and avenues. The wood is used in Southern India for common house building, but it is light and coarse-grained, possessing little strength, and liable to warp. In Burma it is used for yokes and canoes. The fruit and galls are used by dyers.

122 Terminalia coriacea.
| 60 | 4043 | 22351 | 800 |
3, 191.

A large tree, common in the forests of Central and Southern India, of which the heart-wood is one of the most durable woods known; reddish brown, heavy, tough and durable, very fibrous and clastic, close and even-grained: used for beams and posts, wheel and cart-building generally, and telegraph posts. It is durable under water and is not touched by white-ants.

123 Terminalia glabra.
| 55 | 3905 | 20085 | 840 |
160.

This valuable timber tree is found in all the teak forests of India and Burma, furnishing a very hard, durable, strong, close and even-grained wood, of a dark brown colour, obtainable in large scantling, and available for all purposes of house-building, cart framing and furniture.

124 *Terminalia tomentosa.
13, 81, 256.

A valuable forest tree of Malabar, Nagpore, Rajmahal, Oudh, etc., which supplies a heavy, strong, durable and elastic wood. It is, however, a difficult timber to work up, and splits freely in exposed situations. A good wood for joists, beams, tie-rods, etc., and for railway purposes, and is often sold in the market under the name *sal*, but it is not equal to that wood.

125 Thespesia populnea. (*Malvaceæ*).
| 49 | 3294 | 18143 | 716 |
211, 212, 235, 236,

The *Portia* tree of Madras is much used for avenues from its handsome appearance. It grows most rapidly from cuttings, but the trees so raised are hollow-centred and only useful for firewood. Seedling trees furnish a pale red, strong, straight and even-grained wood, easily worked; used for gun-stocks and furniture.

No.	W	Ed	Ft	p	
126	*Trewia nudiflora. (*Euphorbiaceæ*). 240.				This is a large tree, from 40 to 60 feet in height, furnishing a white, soft, but close-grained wood.
127	Ulmus integrifolia. (*Ulmaceæ*). 77.				This large *Elm* is found in various parts of India, from the foot of the Himalayas to Ceylon. It furnishes strong wood employed for carts, door frames, etc. There are other species of elm, *Ulmus campestris erosa*, etc. Growing in the N.-W. Himalaya. lofty handsome trees, often planted as sacred trees by temples.
128	Ziyzphus Jujuba. (*Rhamnaceæ*). 18, 103.	58	3584	1841	672	The *Jujube* or *Bər* is a small thorny tree found growing all over India and Burma, and is cultivated on account of its fruit. The red dark brown wood is hard, durable, close and even-grained and well adapted for cabinet and ornamental work. The leaves are extensively used to feed cattle in the Punjab.

INDEX TO INDIAN TREES.

List of local Synonyms of the trees enumerated in the preceding list.

be *Bengali*, bu. *Burmese*. c. *Canarese*. e *English*. g. *Garhwal*. h *Hindustani*. k *Kunwari* te. *Telugu* ta. *Tamil*.

*These figures refer to the Nos. in the preceding list.

APPENDIX C.

THE BENGAL IRON AND STEEL COMPANY, LIMITED.

(BARRAKUR IRON WORKS.)

Note by MR. J. ANGUS, *Consulting Engineer, dated the* 30*th December*, 1918.

Introduction.

These works were originally established in 1875 by the Barrakur Iron Works Company, but after many vicissitudes were closed in 1879. A few years later Government took over the plant then existing, and, after making some additions, the works were re-started. They were carried on by Government for about 8½ years when they were acquired by the present Company in 1889. Very little of the works, as they then stood, now remain.

At that time the plant consisted of two small open top furnaces—one only being worked—for which the blast was heated by coal in pipe stoves and one blowing engine, with its complement of boilers, which were entirely fired by coal. The production of pig iron in 1889-90 was 9,000 tons per annum This was mainly disposed of to Government establishments, either as pig iron or in the shape of castings.

The foundries then covered an area of about 12,800 square feet and the production was 3,800 tons per annum.

No collieries were then owned by the Works, all the fuel required, either coal or coke, being purchased.

When the Works were taken over by this Company, an immediate start was made to remodel the furnace plant. One new furnace (no. 3) was built on modern lines, as well as three 17′ diameter Cowper stoves for heating the blast. The other furnaces were remodelled and converted into "Gloss-top" to enable the furnace gas to be utilized for the purpose of firing the boilers. These furnaces have, however, been since removed and replaced with new ones (no. 1 and 2).

Description of Works.

The Works are situated at Kulti, on the East Indian Railway, 142 miles from Calcutta.

The Company's properties comprise Blast furnaces, iron foundries, engineering shops, collieries and iron ore mines.

Blast Furnace Plant.—This consists of four furnaces 60 feet high connected with which are 16 stoves for heating the blast. Thirteen of these are 65 feet high by 21 feet dia. and three are 55 feet high by 17 feet dia. Turbo Blowing Engines are connected to the furnaces with a total capacity of 115,000 cubic feet of air per minute Twenty-four Lancashire boilers in two batteries supply steam to the Blowing engines. These boilers are fired by waste gas from the Blast furnaces. The Iron-Ore, Coke and Limestone are delivered from Railway Wagons at back of the furnaces and raised to the charging hoppers by two steam hoists. The slag is removed from the furnaces in ladles on trucks and is taken to the slag tip in a molten state. The furnace plant has productive capacity of 120,000 tons of pig iron per annum.

The Pig Iron of "Bengal" brand is made from selected ores and compares favourably in quality with the best Middlesbro' foundry iron. The Company also manufacture

a special iron brand "Manaharpur" which is superior to any iron imported into India with the exception of hematite iron.

The Pig Iron is supplied to all the principal Railways and Iron foundries in India. In addition, the iron is exported to Ceylon, Straits Settlements, Australia and New Zealand.

Iron Ores.—All the ores consumed are drawn from the Company's properties in the districts of Burdwan and Singbhoom.

A deposit of high grade ore was opened up in the latter district in 1910. The deposit is connected with the Bengal Nagpur Railway by a light railway line—16 miles long—constructed by the Company.

With the high class ores, now at the disposal of the Company it is possible to supply pig iron of any ordinary analysis, except hematite iron.

Coke Plant.—This consists of three batteries each of 34 Simon-Carve's bye product ovens with an outturn capacity of 130,000 tons per annum. The coal is discharged from the railway wagons into a hopper, whence it is elevated to the crushing machine and, after being crushed, is again elevated to the storage bunker, which has a capacity of 800 tons.

From the storage bunker the coal is taken to the compressor, where it is compressed under the stampers, into a cake, ready to be pushed into the oven. The compressor travels the length of the battery and also carries the ram for pushing the coke on to the bench for cooling and removal.

The waste heat from the ovens passes to the battery of boilers where it is utilised in raising steam for the generation of electric power, which is partly used at the ovens and partly carried to the Works. The Crusher, Elevators and Compressor are operated by electric power.

When the coke is discharged from the ovens, it is quenched, loaded into barrows and removed direct to the Blast furnaces for consumption.

Foundries.—This department consists of pipe foundries, Railway sleeper and chair foundry, general casting foundry and brass foundry, and covers an area of 175,000 square feet.

(a) *Pipe foundries.*—These include two plants for the manufacture of cast iron pipes made in dry sand moulds and vertically cast. One plant is fitted with hydraulic power and the other with electric power. All pipes are coated with Dr. Angus Smith's solution and tested to any hydrostatic pressure required.

Flanged pipes of all sizes for steam or water mains are made.

(b) *Railway sleeper and chair foundry.*—This foundry is fitted with moulding machines for making cast iron railway sleepers—plate or bowl designs—and railway chairs. Sleepers and chairs for any type of rail are made.

(c) *General foundry*—All kinds of castings (up to 10 tons weight) for general purposes are made here, including columns for public buildings and mills, straining posts and sockets for railway fencing, mortar mills and road rollers and machinery castings for engineers, etc. Ornamental columns, lamp posts, railings, etc., are also made.

All classes of special castings for water works' requirements are also manufactured.

(d) *Brass foundry.*—Castings for engineers' requirements are made.

The foundries are capable of manufacturing 60,000 tons of castings per annum as follows:—

Pipes	..	..	..	15,000 tons per annum.
Sleepers and chairs		..	..	30,000 „ „ „
General castings ..		..	..	15,000 „ „ „

Stock averaging over 3,000 tons of cast iron pipes, from 2" to 12" bore with plain, turned and bored or double flanged joints are kept on hand, in addition to substantial stocks of "I S. R." fencing sockets and straining posts, railway chairs, etc

Engineering shops.—These include machine shops, smith's shops, riveting and erecting yards, and are equipped for general work and repairs.

Collieries.—The Company's collieries are situated at Khandwa and Ramnagore (Raneegunge field) and at Noonidih (Jherria field).

The present raising of coal is about 150,000 tons per annum, but is capable of being increased to 250,000 tons, all of first class quality coal. The Company's requirements are drawn from these collieries, in addition to supplying railways and general consumers.

APPENDIX D.

INDIAN METALS.

1. IRON.—*Beypore.*—The bulk of these ores are rich magnetic oxides, and when freed from earthy matter and ready for the blast furnace, contain about 72 per cent. of iron. They are found in mountain passes and are obtained by quarrying with a crowbar. The quantity is so large that it is not necessary to have recourse to underground operations. They are quite free from sulphur, arsenic and phosphorus, and upon a large average have been found to yield 68 per cent. of metal in the blast furnace.

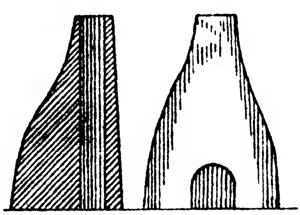
2. *Salem.*—The iron of the Salem districts of the Madras Presidency is a rich magnetic oxide of iron, very heavy and massive. The yield averages 60 per cent. of metallic iron. The ore is, however, often mixed with quartz, which is a very refractory material in the blast furnace. Limestone and, in some places, shell lime is employed as a flux, and the charcoal of some kind of acacia is the fuel.

The method of smelting is here, as in other places, very simple, and the apparatus used very cheap. The iron produced is of excellent quality, but the quantity is but small.

The shape and construction of the furnaces vary slightly, but that most generally used is nearly cylindrical, tapering into an irregular cone at the top The furnaces are constructed entirely of red-clay mixed with sand ; they constantly require to have the inside renewed by fresh linings of clay, which cannot stand more than three or four days' working. The height of the furnace varies from 3 to 5 feet, with a diameter of the interior of from 9 inches to 1 foot. The furnace itself at the ground is about 2 feet wide and tapers sometimes from the ground, sometimes from about ⅓rd or ¼th of the height; the walls are from 4 to 6 inches thick. The front of the furnaces is for the most part nearly vertical, the back therefore slopes considerably more than do the sides, as shown in the annexed figure, giving a section of an iron furnace at Chaindanumgalum in the Namkul Taluq. In some cases, however, the furnace is a regular cone.

Inside the furnace, the ground is generally excavated to the depth of about 1 foot to form a hearth for the bloom. A semi-circular opening from 1 foot to 14 inches high is either left in the front wall, or is subsequently cut into it while the clay is still moist. This is filled up with clay before the commencement of each smelting.

Native iron furnace.



The blast required for the smelting is obtained by using two bellows, each made of a sheep or goat's skin, and worked by hand in the ordinary way by a man squatting in front of the furnace. The nozzles of the bellows are made either of thin sheet iron or tin plate, or sometimes of bamboos, and these are inserted into a clay tuyere entering at the bottom of the front opening and carefully luted. The tuyeres reach to the centre of the furnace. The bottom of the furnace is covered with a layer of charcoal dust to prevent the adhesion of the bloom. By using the bellows alternately, a tolerably continuous blast is produced.

The furnace is first filled to the top, or very nearly so, with charcoal, which is ignited by means of a burning ember passed through the tuyere. As soon as flames issue from above, a small charge of the powdered iron ore, well moistened to make it cake together, is introduced through the apex and covered with charcoal; this is followed by successive charges of ore and fuel, until the proper quantity of ore is in the furnace. The blast is now strongly applied, and continued from two and a half to four hours, according to the size of the furnace. The process is then considered complete, the semi-circular aperture in front of the furnace is opened and the bloom is removed. A number of heavy blows with a hammer or mallet are given to knock off as much as possible of the adhering oxide, and the bloom is then cut half through with a hatchet, and allowed to cool. The object of cutting open the bloom in this way is to exhibit the grain to the purchaser.

Charcoal is the only fuel used, but different values are attached to different woods for the purpose of charcoal, and frequently two or three different kinds are used at different levels in the furnace. What the effect of this may be cannot be clearly stated. No flux is used.

The ordinary charge for one of these furnaces is about 18 lbs. of ore, and the smelting occupies two to three hours. The average out-turn is three blooms in the 12 hours, four men being required to work the furnace; but the furnaces are never worked continously. In some parts, larger furnaces are used, and the charge for each smelting amounts to 35 lbs of ore.

The process of refining the metal thus obtained consists merely in heating the bloom several times, subjecting it to a good hammering, by which the slag is in great measure got rid of. It is then hammered into rude bars about 1 foot in length and about 2 inches in width. From these bars the "Wootz" or Indian steel is prepared.

3. *Cuttack.*—An abundance of this ironstone is found in the district of Sambalpore, and it is plentiful in the Cuttack Tributary States of Talehere, Dhenkanal, Pal Lahara, and Ungool, and indeed throughout the hilly country bordering the settled districts of this province on the north-west. The whole of the iron used for various purposes in this division is supplied from these local sources. In Sambalpore, the crude iron is sold at one anna per seer, which is equivalent to about three-fourths of a penny per English pound. No flux is used; the broken ironstone is mixed with charcoal, which can be prepared in any required quantity on the spot, and the mixture is then, probably in alternate layers, put into the furnace,—a kiln in miniature standing about 4 feet high, and made of clay. The top is open, and the bottom and sides thoroughly closed. The fire is maintained by an artificial blast, introduced through a fire-clay pipe which is sealed up with clay after the insertion of the nozzle of the bellows. The slag escapes, or more properly is raked out, through an aperture made in the ground, and which runs up into the centre of the furnace base. Three men—one to serve the fire, and two to work the bellows—are required to tend each furnace. The charcoal used is made from the Sal or *Shorea robusta.* Limestone in calcareous nodules is abundant on the spot, but is nowhere used in smelting.

4. *Shahabad.*—Abundant quarries of the peroxide and proto-peroxide of iron as also of iron-pyrites, abound in the most accessible portions of the Kymore range The Kymore range is the north-easterly spur of the Vhyndhia range, and fills all Southern Mirzapore and Shahabad. Most of the ores are peculiarly rich in metal, some of them even yielding 70 to 75 per cent. of Pig-Iron, but without accessible coal they are comparatively useless. Considerable quantities of iron, and that some of the best in India, are annually produced in Palomow, Rewah, Bidjugghur, and Singrowlie. The

iron from the latter place, in particular, bears a high character in the market, being tough, flexible, and easily worked, while English iron, having originally been smelted from an inferior ore (the clay ironstone) and with mineral coal, is almost unworkable by native blacksmiths.

The ores are extremely rich and the cost merely nominal, probably not more than 2 per cent. upon the cost of quarrying, and the ores being all above ground would reduce the cost of quarrying to a minium. Charcoal, as used by native smelters may be obtained at 10 or 11 maunds per rupee, Rs. 2½ to Rs. 3 per ton, in the forest to which, of course, must be added cost of carriage to site.

5 *Jubbulpore.*—The Azureea mines are situated on a hill consisting of iron ore, found at 1½ feet from the surface, and extending over an area of about 60,000 yards square and 30 feet deep. The ore exists in thin *flakes* of a grey iron colour and metallic lustre. The nature of fuel used is common wood charcoal, and for refining the metal, bamboo charcoal; the fuel is brought from a distance of about 5 miles from the mines. The ore and charcoal are thrown, in small quantities, every half hour, into an earthen furnace five feet high and two feet square; a part of the bottom of the furnace is filled with fuel only; this bring kindled, a pair of bellows is applied to raise the heat, and a passage made at the side of the furnace for the melted metal to run out. Four maunds (320 lbs.) of ore and 2½ maunds of chacoal are daily used in a furnace; the fuel is used in the proportion of 5-8ths or 62 per cent. of the ore for smelting, and 1-5th more for refining the metal. A furnace furnishes daily two maunds (160 lbs) or 50 per cent. of the crude iron from 4 maunds of the ore; this when forged, yields, 30 seers, or nearly 19 per cent. of wrought-iron. The ore is simply dug out with pickaxes; it costs 6 pie per maund for excavating and carrying to the furnace. The fuel ,or charcoal costs Rs. 1-1-6 per maund, of wrought iron. The entire cost of the pure metal obtained amounts to Rs. 1-13 per maund, including labour and materials. The ore is generally sold at the works and conveyed on bullocks to different markets. When brought to Jubbulpore, the nearest market, it costs 2 annas 8 pies per maund, exclusive of duty.

6. *Punjab.*—The iron ores of the Punjab are produced along its north-eastern mountain frontier as well as in the lower hills of the Sulaimani and Waziri ranges and those to the south-east of the Bunnnoob district, and to some extent in the Salt range. On the other side of the province, in the hilly portions of Gurgaon district iron is found, although the hills in the Delhi district exhibit no specimens of iron ore as such, there is in them a ferruginous rock; and the Mahruli hill, which yields iron ore, one of that group of outliers that forms a continuation as it were of the Aravalli range, and property within the Delhi district.

Along the Himlayan frontier, the principal places of production are the Hill States of the Simla district (Jubal, Dhami, Bishahr and Rampur). Again at Suket and Mandi, iron is largely produced, and the mines at Kot Khai, Fatihpur, and Bhir Dangal of Kangra are famous. Pursuing the line of Hill States the iron of the Chamba hills next demands notice, the next division up to the Hazara district is included in the territories of H. H. the Maharajah of Kashmir. In these territories, the best iron is found at Reyatsi in Jummu, while the iron found at Sonf and Kutyar in Kashmir proper, is not so good. Iron of good quality, but inferior to that of Reyasi, occurs in Bunch, the territory of Raja Moti Singh, feudatory of Kashmir. Reverting once more to British territory, we find iron ore at Bakot in the Hazara district. Next to this, in the hills due north of Peshawar, is the source of the Bajaur iron, which is of fine quality, and is used in the manufacture of the g un barrels of Kohat

and Jummu and not a little also, it may be presumed, in the formation of steel for the blades of Bokhara and Peshawar.

Nowhere within British territory is indigenous steel procurable, at all events such steel as would be of any use in the finer classes of manufacture; the cutlery of Nizamabad and Guzrat is exclusively manufactured with imported steel, while the inferior kinds are not steel at all but merely polished iron.

The iron ores of the Himalayan districts are mostly magnetic oxides of singular purity, and exist in a great measure in the form of an iron sand or aggregate of particles of oxide of iron. These are no doubt produced in the detrition or disintegration of schistose and micaceous rock containing particles of metal; this kind of rock or ore is called "pathar dhon."

In other places the ore is found as a massive hematite, and is sometimes associated with copper. In Suket, and a few other localities, a glistening micaceous iron ore or glistening hæmatite occurs, but the natives often call it "antimony of Ispahan" (surma Isfahani). In one or two instances it is exhibited as a hydrated peroxide

Iron exists at Kanigorum in the Waziri hills; it is found also as a hematite in several parts of the Salt range, and in the Chichalli range on the other side of the river. In a few places near the same ranges, and especially associated with shale, this metal is found in the form of a sulphuret, i.e., iron pyrites, and the beds of the "kasis" and "kahi" (earth containing anhydrous proto-sulphate of iron) are said to result from the decomposition and oxydization of these pyrites. Hydrated peroxide in the form of ochre is procured in a number of places in the Punjab, and forms the colouring matter in the "gil-i-zard," or yellow earth, and in the "Multani mitti" used by the dyers.

7. The following account has been received from the Deputy Commissioner of Gurgaon: "The hill from which the iron is obtained in Firozepur is known generally by the name "Jharkah," and the iron mines in it are called "bura" mines, in which by digging to a depth of 6 feet pieces of a red and slightly glistening hematite are obtained, called "bura." From this ore iron is obtained. In digging for the ore, the miners first come upon a quantity of red earth and soft stone discolored by iron, which is used to make roads with; below this the hæmatite is found. The ore is first pounded with stones into small fragments and then taken to the smelting furnace, which is called "nandri." This furnace is of a round conical shape, narrow at the top and wide at the base, and about 9 feet high; into it is put 13 maunds of the ore (this quantity of ore is called a "gan") and 12 maunds of charcoal,—some of it above and some below, the crushed ore. Each furnace is fitted with two pairs of bellows, which are worked to supply a blast of air to the fire during eighteen hours continuously; the melted iron falls to the bottom. Thirteen maunds (= 1 gan) of ore yield 8 maunds of metallic iron,—this is taken out and repeatedly heated and hammered till it becomes pure, when about 1¼ maunds of the unmixed metal remain; in thus bringing the iron to its pure state ("loha pakka"), 5 maunds of charcoal are required besides the 12 consumed in the smelting furnace. Thus to completely work 13 maunds of ore, 17 maunds of charcoal are required at a cost of Rs. 8-8, (at 2 maunds per rupee); the total cost of the process is Rs. 10-10, thus:—

	Rs.	a.	p
Charcoal, 17 maunds, ...	8	8	0
Wages of workmen at the smelting furnace	0	10	0
Wages of workmen at the bellows and those who hammer out the iron ..	0	12	0
Wages of workmen who work the metallic iron by repeatedly heating it, etc.,	0	12	0
Total ..	10	10	0

8. The following are the kinds of iron to be met with in the Lahore bazar:—second class steel, "asbat," used for coarse cheap cutlery purposes.

Iron, variety "khéri," used for agricultural and other implements

Iron, variety "barki,"

Iron, variety "guléri," comes from Gwalior in Hindoostan; it is a tenacious metal and used for wire drawing, gun barrels, etc.

Besides these varieties, the following kinds are met with in the shops of the "lohtis," or iron sellers, who are the persons who buy wholesale from the Naurias and other merchants and then sell by retail to the blacksmiths, or "lohars." Of Indian iron, the varieties are—the "khéri," noted above; this is said to be brought from Hindoostan, it is an iron of unpromising appearance, but exhibits on being forged its superior quality; it is much employed for carpenters' tools, adzes, etc., and occasionally for swords. It values about 4 seers per rupee; its probable origin is the Jaipur territory.

"Faulad" or steel, used to be imported from Hindoostan for the manufacture of armour, shields, etc.; at the present day when the manufacture of such armour is not carried on, the import has ceased, the steel used to be brought in "chaktis" or circular discs, about ¾ of an inch thick. "Guleri" iron, which is sold in pigs, and values Rs. 6-12 per maund, is a tenacious iron used also in wire drawing. The imported Indian irons are brought up by Naurias to Hatras between Allygurh "and Agra, and from thence taken to Amritsar, which is the Punjab Mart." Of Punjab iron, the "bajauri," from Bajaur, north of Peshawur, is not much exported to the central plain districts, though it was formerly, for the purposes of gun making. Bajauri is still largely used at Khat in tuho remarkable process of their gun barrel making, and is used also at Kalabagh and other places. The guns and cutlery made at Nizam abad, in the Gujranwala district, are of "guleri" iron or of asbat. "European" steel is also employed for cutlery.

Barki iron is brought down from Suket and the Mandi mines, it values Rs. 6-12 to Rs. 7 a maund, and finds its way on backs of mules and donkeys to Dinanagar whence it comes to Amritsar; it is probable that other irons of the Kangra district mines are similarly imported under this name. Attempts have been made by individual traders to bring down the iron of the Chamba territory, but the cost of carriage is too great to render it profitable, and it is seldom imported.

The other irons of the bazar are European and brought from Bombay; the varieties are,

The "glaspatti," an iron sold in long flat bars; it is used for making tires of wheels, etc., value Rs. 6-12 a maund.

"Gold sink," thick pieces of iron, value Rs. 7 a maund; and also "gol kandla," a similar iron, but in thinner bars, value Rs. 8 a maund.

"Chadar," or sheet iron, value Rs. 8 a maund, is employed in making "tavas" large iron cauldrons, etc.

"Chakor sink" and "chakor kandla,"—are varieties of iron, imported in long rods, 16 feet or so, about 3 inches broad and ½-inch thick,—this sells at Rs. 9 a maund. When the rods are thin it is called "chakor kandla," and fetches Rs. 7 per maund.

These bars are stamped with a European trademark when of the first quality; these are the most approved, and are called "sacha chakor," (genuine, "chakor,") and fetch Rs. 9-8. If these bars are only the same in shape without the stamp, they fetch Rs. 9 and Rs. 7, as above-mentioned.

Another variety is "asbat," a hard but brittle kind of steel, selling at 3½ seers per rupee; it is imported in bars, and used for tools on account of its hardness.

A kind of iron is sold in the bazars called "falli," being sold in pieces of a fusi-form shape, tapering at each end. This is probably a hill iron.

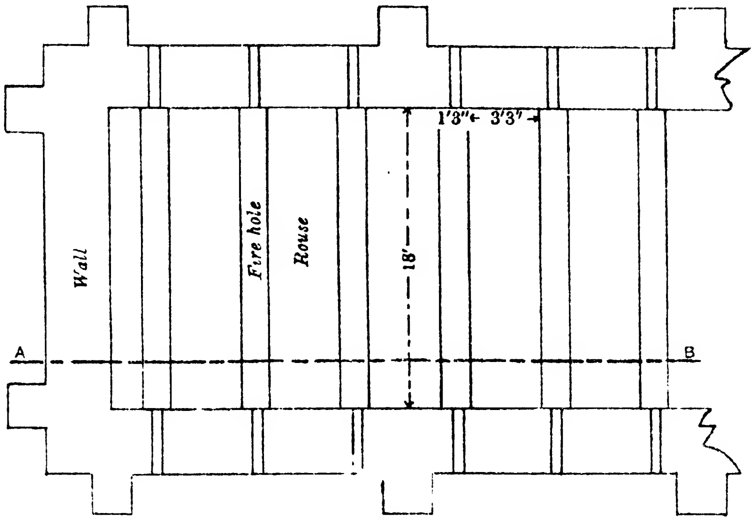
Raniegunge.—Iron is also found in considerable quantities in the Raniegunge district, near the famous coal fields, but the amount of sulphur present in this coal prevents its being satisfactorily used for smelting the iron.

9. COPPER.—The fuel used for smelting, is charcoal made from the extensive forests in the immediate vicinity of the mines and works in Landoo, in Dalbhoom and Singbhoom, in the south-west frontier of Bengal, about 140 miles from Calcutta.

Copper is found in the Goorgaon and Hissar district, also in Kangra, the Salt range and Kashmir. In Hissar the ore is obtained by mining the hillside; the work is carried on only by day, and then with the aid of lamp light. Occasionally a rush of water causes the work to be stopped, and as there is no mechanical contrivance for controlling the flood, not unfrequently the particular spot has to be abandoned altogether. The ore obtained from the mine is broken into pieces and smelted sufficiently to make it cake; on this, wood and the common "upla" (dry cow dung) of the country are heaped and the mass set on fire. The process of extracting the metal is similar to that of burning lime; the copper contained in the pulverized and caked mass, percolates through the calcined refuse and finally forms irregular shaped fragments at the base.

10. TIN.—*Malacca.*—Charcoal made from the Gomposs tree, is the only description of fuel employed. A funnel-shaped blast furnace, 6 feet high and 4 feet diameter at the mouth is used. The sides of the trunk and funnel-hole are shaped and backed with clay. The fused matters escape from the cavity and flow continually into an exterior reservoir, hollowed out for that purpose, from which the liquid metal is ladled out into moulds, shaped in moist sand. The trunk is filled with charcoal, and combustion is accelerated by a cylindrical blowing machine, worked by eight men. When the whole mass is brought to a red heat, the crude ore is sprinkled on top of the burning embers and kept constantly fed by successive charges of charcoal and mineral. Each charge consists of 30 piculs of washed ore, containing from 45 to 60 per cent. of tin.

Antimony and lead are found in several districts of the Punjab, but apparently are not much worked.



ENLARGED SECTION ON A B.

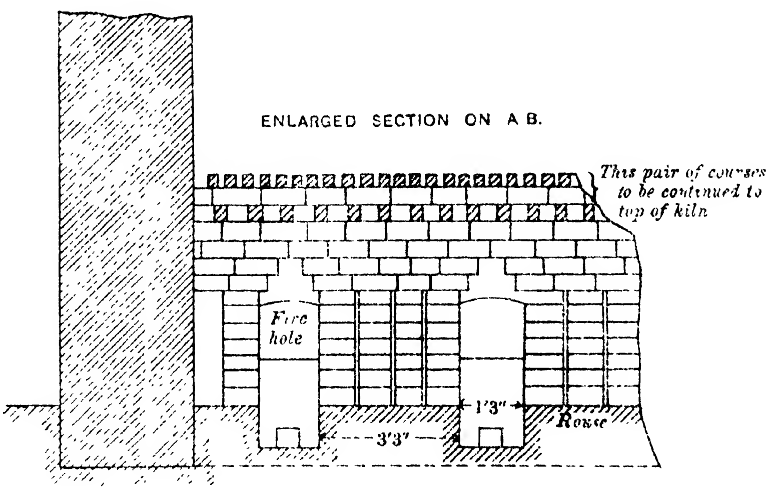
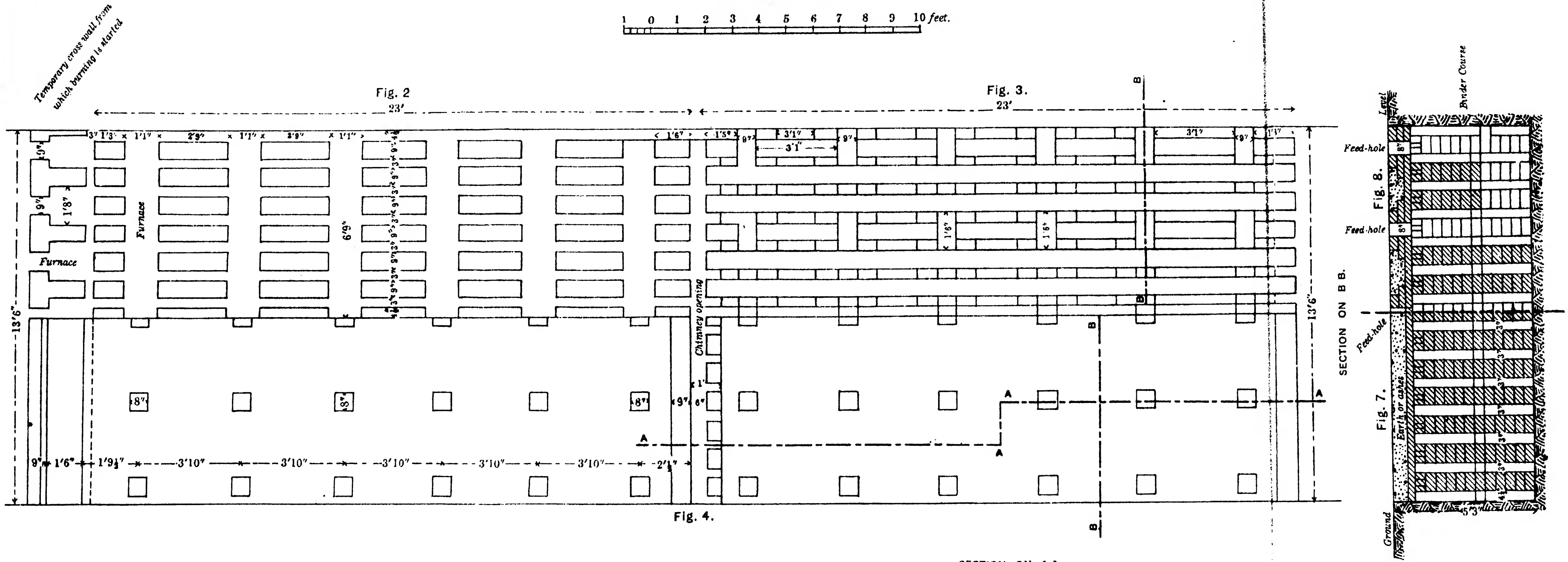
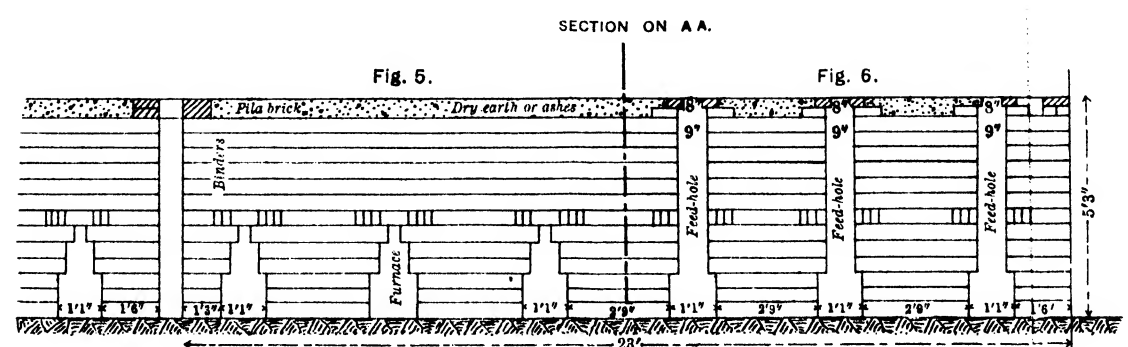


Photo. Zinco, September, 1924.—No. 1952 1-2000

BULL'S PATENT TRENCH KILN.

Scale—4 Feet = 1 Inch.





In a Circular kiln, with the exception of the distance from centre to centre of furnace being greater on the outer face and less on the inner, the plan of the setting, chimney openings and chambers is exactly the same as in the straight portion here shown. Should it be found convenient to work with a greater distance from centre to centre of furnaces, it is obvious there is nothing in the kiln itself to prevent it. The templet for setting the bottom brick can be made for any distance from centre to centre of furnace.

Photo. Zinco., September, 1924.—No.1952-2-2000

PLATE III.

BULL'S PATENT TRENCH KILN.

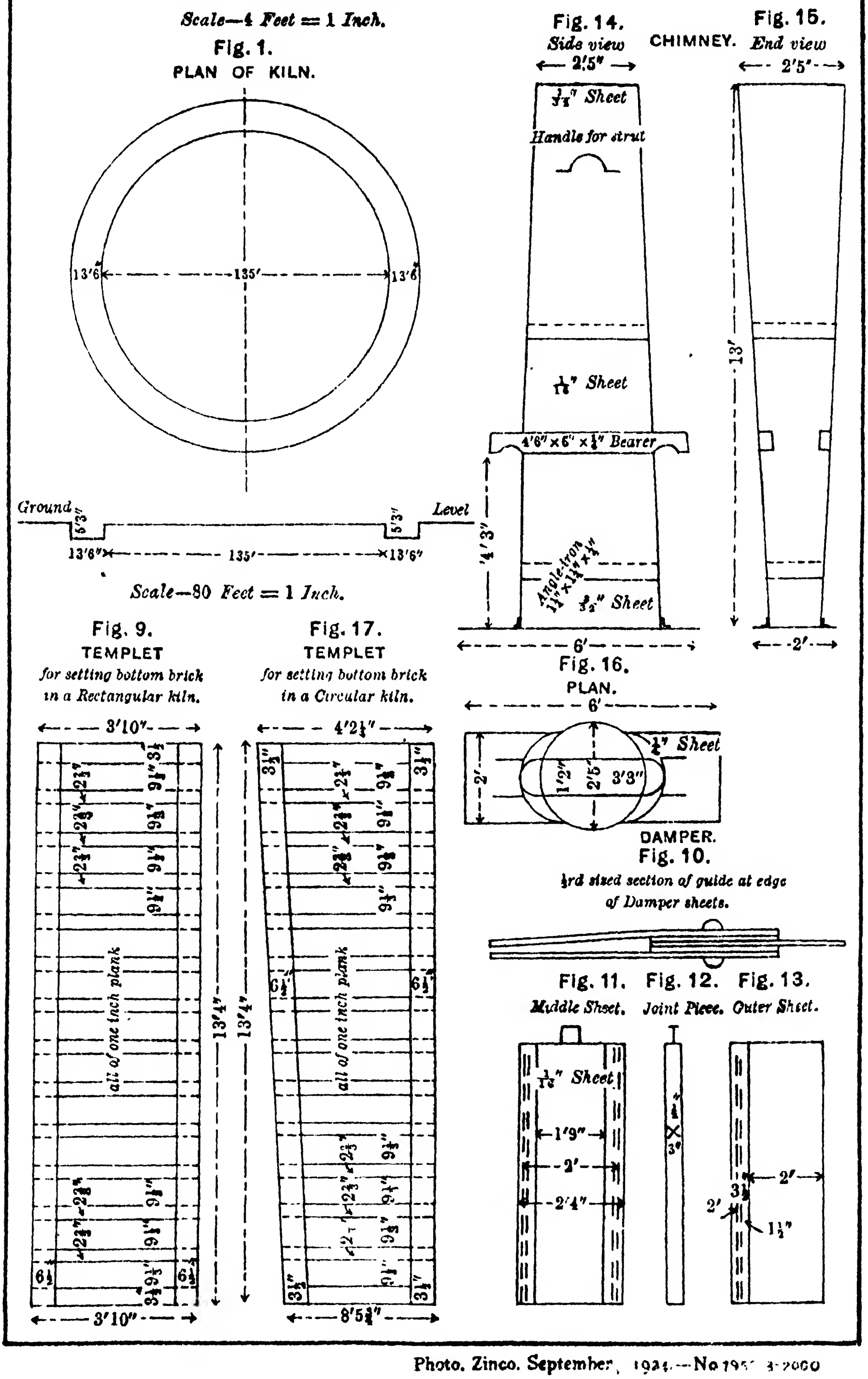


Photo. Zinco. September, 1924.—No 195 3-2000

SECTION OF A PUG-MILL.

For preparing Clay for Brick making.

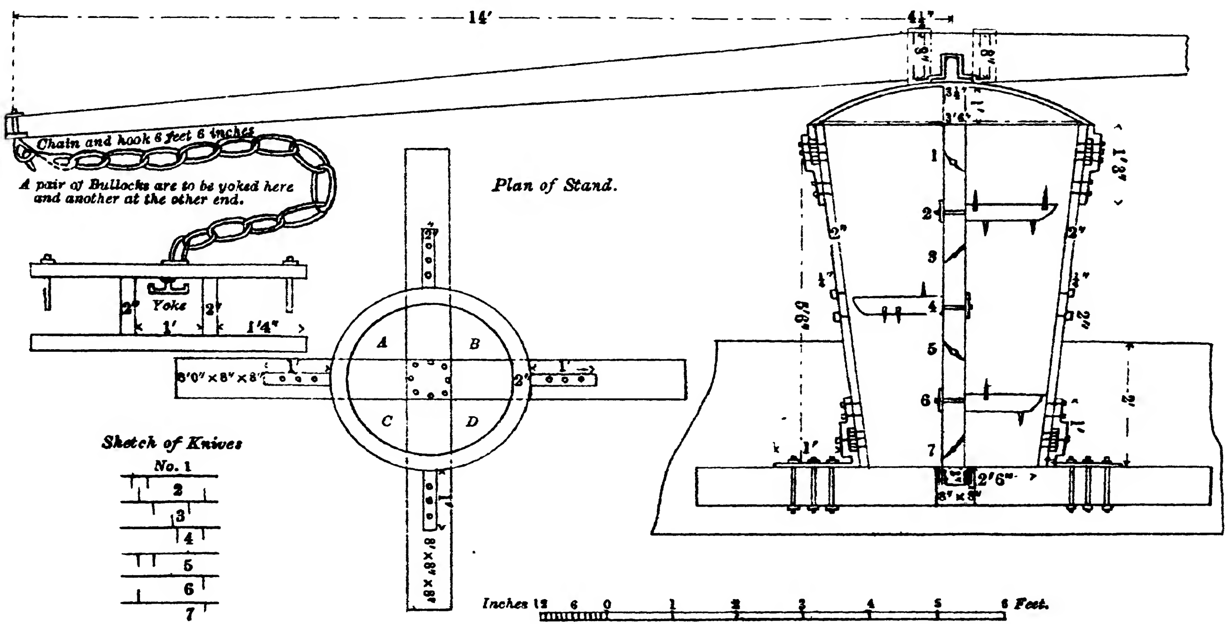


Photo. Zinco., August, 1924 —No.7358-4.2000

PLATE V.

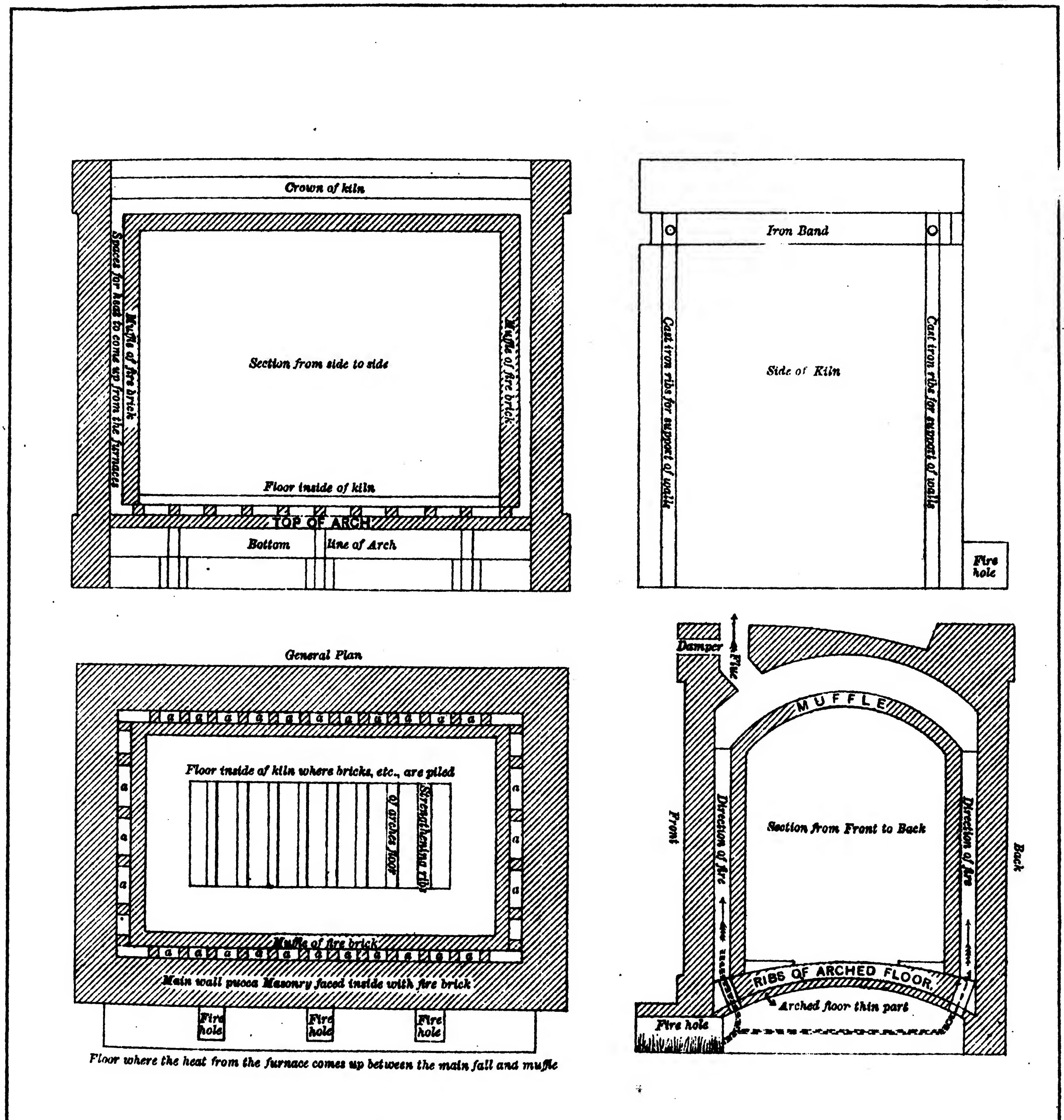


Photo. Zinco. August, 1924.—No.

PLATE VI

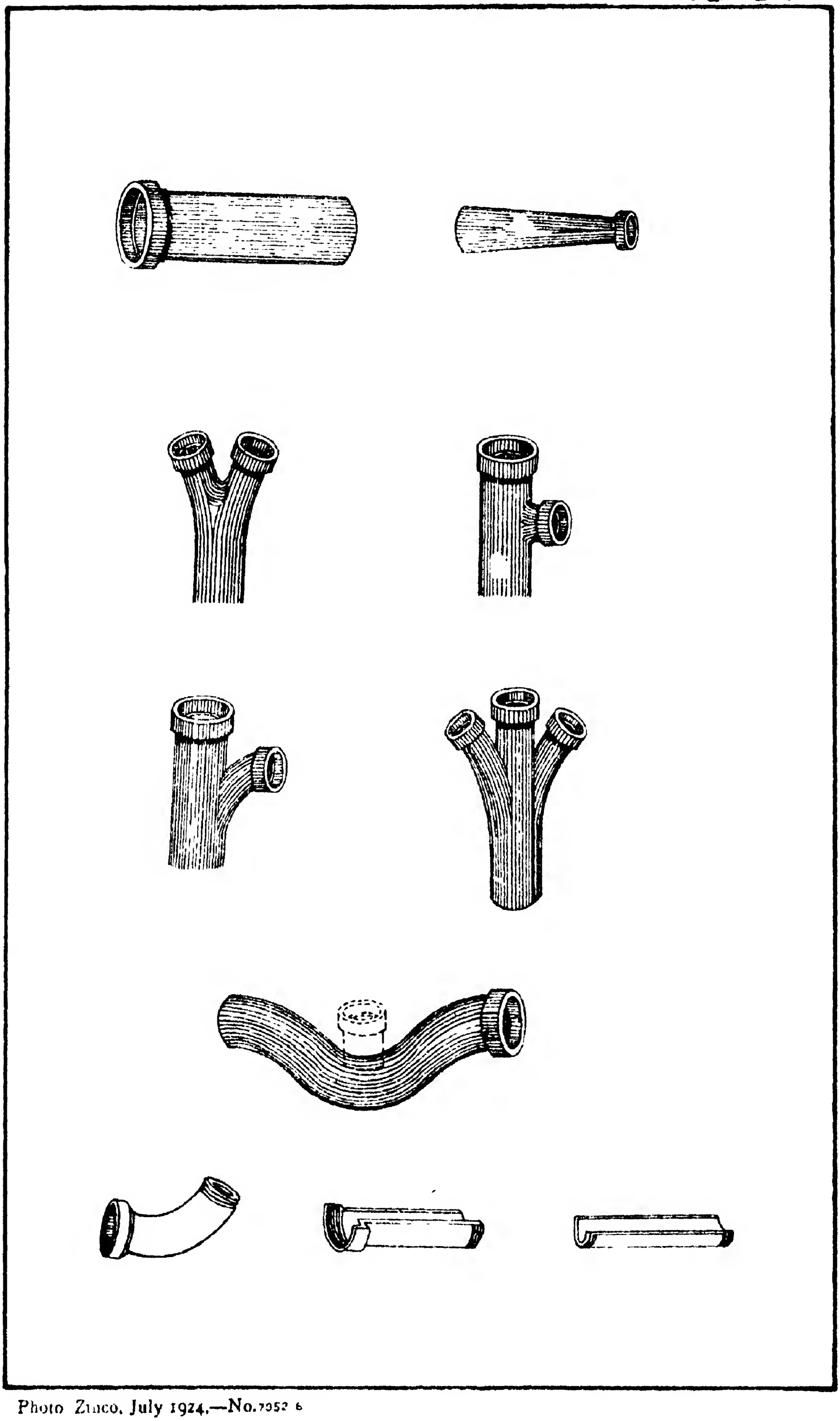


Photo Zinco, July 1924.—No.7352 6

LIME KILN.

This may be built singly or several can be built together in a block, according to requirements, each kiln will burn about 150 cubic feet per day.

Fig. 1.

SECTION.

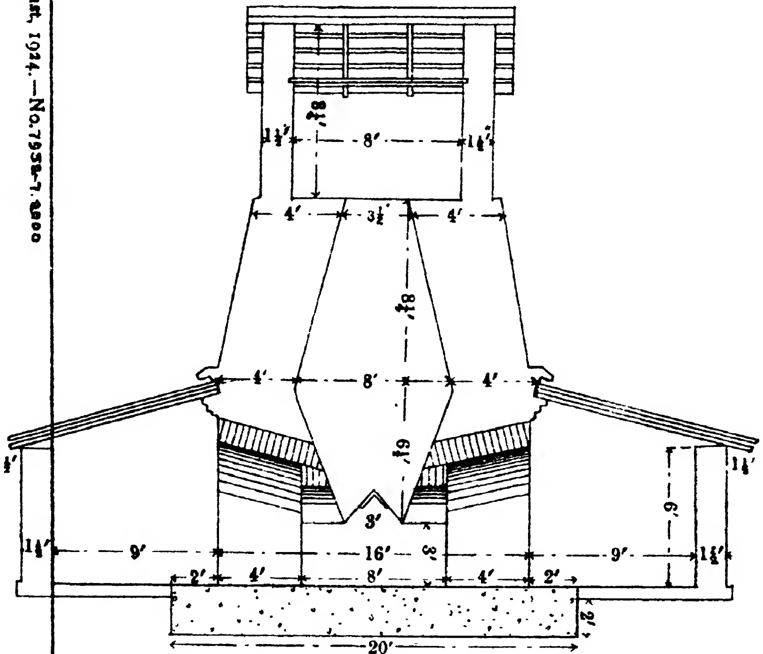


Fig. 2.

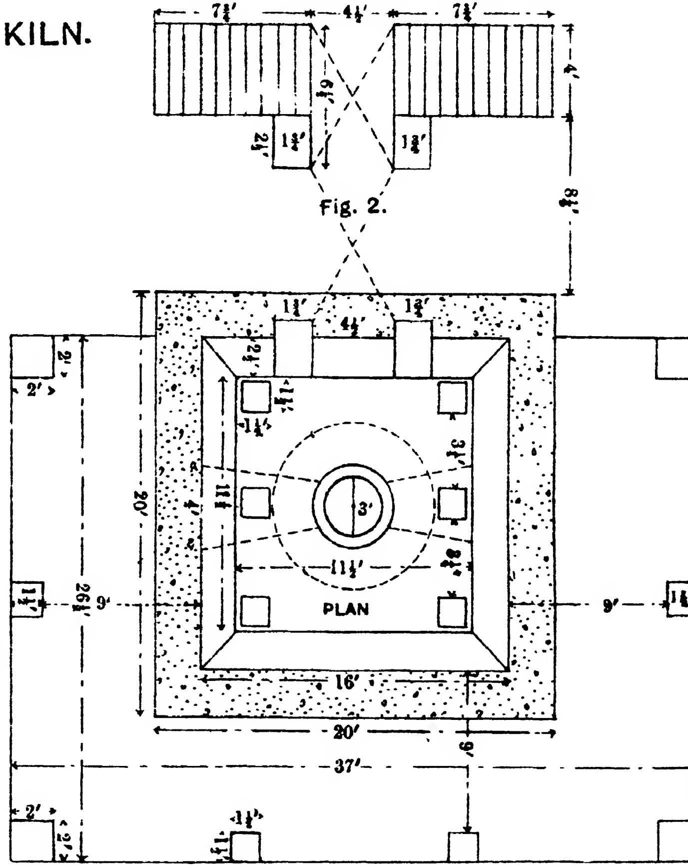


PLATE VII.

Photo. Zinco., August, 1924.—No.7958-7.2800

DEHRA DOON LIME KILN.

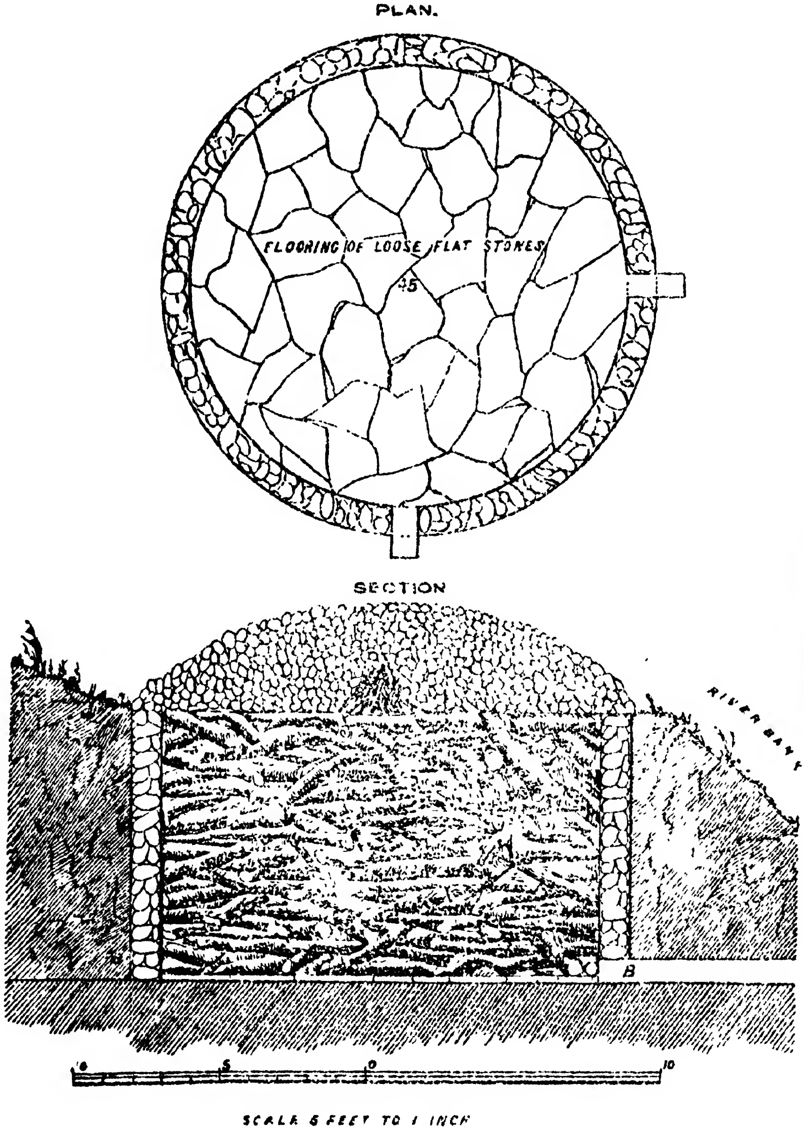
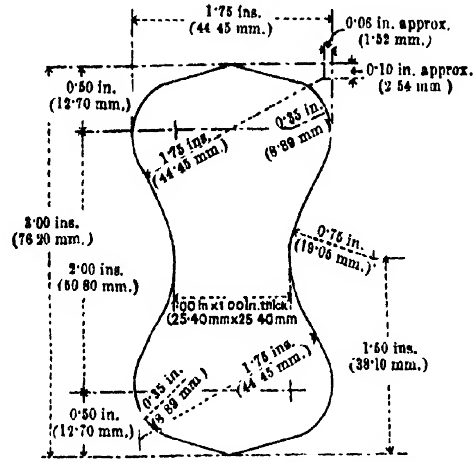
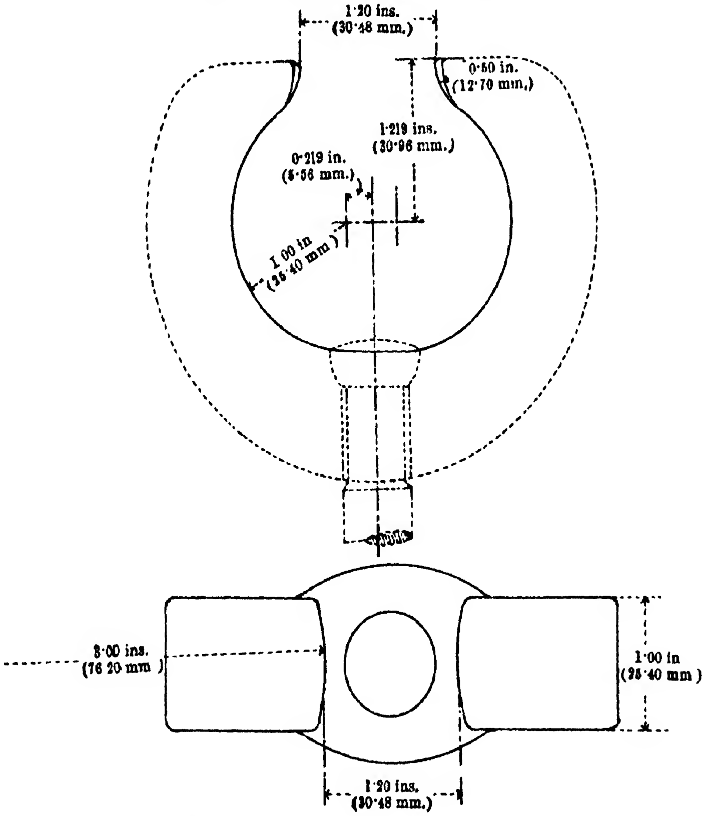


Photo. Zinco., August, 1924.—No. 1952-8.2000



Briquette to have an uniform thickness of 1 inch throughout.

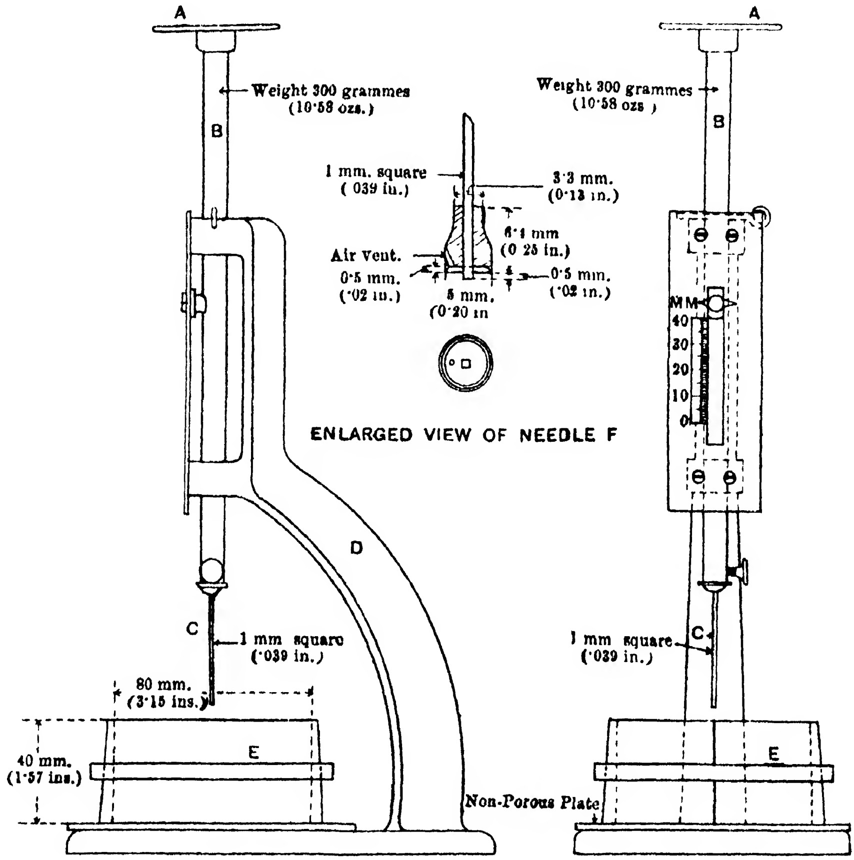
Fig. 1. Dimensions of Standard Briquette.



Figs. 2 and 3. Elevation and Plan of Jaws for holding Briquette.

Photo. Zinco., July, 1924—No. 7852-8

VICAT NEEDLE APPARATUS FOR ASCERTAINING SETTING TIME OF CEMENT.

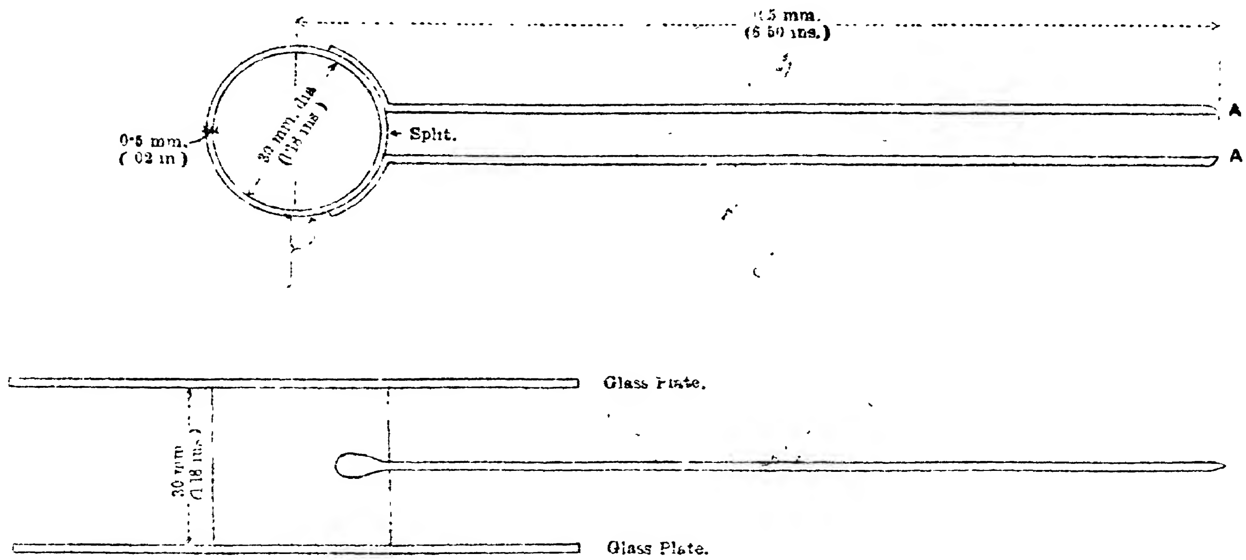


The Vicat Needle Apparatus consists of a frame (D) bearing a movable rod (B) with the cap (A) at one end and the removable needle (C) at the other. The needle shall be 1 mm. (·039 inch square in section and have a flat end. The rod (B) carries an indicator which moves over a graduated scale attached to the frame (D). The cap, rod and needle with all attachments shall together weigh 300 grammes (10·58 ozs) The mould for the cement consists of a split ring (E) 80 mm. (3·15 inches) in diameter, 40 mm. (1·57 inches) high which rests on a non-porous plate.

For the determination of the final setting time the needle (C) is replaced by the removable needle (F) of the same shape and section, but fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm. (0·20 inch) in diameter, the end of the needle projecting 0·5 mm. (·02 inch) beyond this edge. The needle with attachment, the cap (A) and rod (B) complete as above described must together weigh 300 grammes (10 58 ozs.).

Photo. Zinco. July, 1924 —No.7952-10

APPARATUS FOR CONDUCTING THE "LE CHATELIER" TEST.



The apparatus for conducting the Le Chatelier test consists of a small split cylinder of spring brass or other suitable metal of 0·5 millimetre (·02 inch) in thickness, forming a mould 30 millimetres (1·18 inches) internal diameter and 30 millimetres (1·18 inches) high. On either side of the split are attached two indicators with pointed ends A. A., the distance from these ends to the centre of the cylinder being 165 millimetres (6·50 inches).

Photo. Zinco., July, 1924.—No. 7952 II